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B.R. Wells Arkansas Rice Research Studies 2020

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DIVISION OF AGRICULTURE
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Cover Photo: Rick Cartwright, then associate director agriculture and natural resources, inspects late-season rice in a Faulkner County, Arkansas field, 14 November 2011

Photo credit: Kevin Quinn, former extension video specialist, University of Arkansas System Division of Agriculture Communications.

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Arkansas Agricultural Experiment Station (AAES), University of Arkansas System Division of Agriculture, Fayetteville. Mark J. Cochran, Vice President for Agriculture. Jean-François Meullenet, AAES Director and Senior Associate Vice-President for Agriculture–Research. WWW/CC2021.

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University of Arkansas System
Division of Agriculture
Arkansas Agricultural Experiment Station
Fayetteville, Arkansas 72704

DEDICATED IN MEMORY OF
Bobby R. Wells

Bobby R. Wells was born July 30, 1934, at Wickliffe, Kentucky. He received his B.S. degree in agriculture from Murray State University in 1959, his M.S. degree in agronomy from the University of Arkansas in 1961, and his Ph.D. in soils from the University of Missouri in 1964. Wells joined the faculty of the University of Arkansas in 1966 after two years as an assistant professor at Murray State University. He spent his first 16 years at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart. In 1982, he moved to the University of Arkansas Department of Agronomy in Fayetteville.

Wells was a world-renowned expert on rice production with special emphasis in rice nutrition and soil fertility. He had a keen interest in designing studies to determine how the rice plant reacted to different cultural practices and nutrient supplementation: including timing and rates of nitrogen, phosphorus, and potassium fertilization; zinc fertilization of high pH soils; irrigation methods; dates and rates of seeding and the reasons for differing responses.

Wells was a major participant in the pioneering effort by University of Arkansas System Division of Agriculture scientists in the development of the Degree-Day 50 (DD50) computer rice production program which assists growers with 26 management decisions during the season based on temperature, rice cultivar, and growth stage; including herbicide application, critical times to scout and spray for insects and diseases, and nitrogen fertilizer application. The DD50 program developed in the 1970s remains a vital program to this day in assisting growers, consultants and extension agents in making important management decisions concerning inputs to optimize rice yield and quality. Other rice-growing states have followed suit in this important development and have copied the Arkansas DD50 program.

He was the principal developer of the nitrogen fertilizer application method known famously at the time as the Arkansas 3-way split application strategy; who his successor discovered, using the isotopic tracer N-15, to be the most efficient method (i.e., as concerns nitrogen uptake) of fertilizing rice with nitrogen in the world. The application method has since been modified to a 2-way split, because of the release of new short stature and semi-dwarf cultivars, but its foundation was built on Wells' 3-way split method.

Wells was a major participant in the development of cultivar-specific recommendations for getting optimum performance from new cultivars upon their release and reporting research results at Cooperative Extension Service meetings as well as in the Extension Service publications, even though he had no extension appointment; he just did what he thought was best for the Arkansas rice farmer. He made numerous presentations at annual meetings of the Tri-Societies and Rice Technical Working Group, published many journal articles, and several book chapters. He loved being a professor and was an outstanding teacher who taught a course in soil fertility and developed a course in rice production. Both courses are still being taught today by his successors. The rice production course he developed is the only rice production course being taught in the USA to the best of our knowledge.

Wells was very active in the Rice Technical Working Group (RTWG), for which he served on several committees, chaired and/or moderated Rice Culture sections at the meetings, and was a past secretary/program chair (1982-1984) and chairman (1984-1986) of the RTWG. He was appointed head of the Department of Agronomy (later renamed the Department of Crop, Soil, and Environmental Sciences) in 1993 and was promoted to the rank of University Professor that year in recognition of his outstanding contributions to research, teaching, and service.

Among the awards Wells received were the Outstanding Faculty Award from the Department of Agronomy (1981), the Distinguished Rice Research and/or Education Award from the Rice Technical Working Group (1988), and the Outstanding Researcher Award from the Arkansas Association of Cooperative Extension Specialists (1992). He was named a Fellow in the American Society of Agronomy (1993), and posthumously, the Distinguished Service Award from the RTWG (1998) and induction into the Arkansas Agriculture Hall of Fame (2017). Wells edited this series when it was titled Arkansas Rice Research Studies from the publication's inception in 1991 until his death in 1996. Because of Wells' contribution to rice research and this publication, it was renamed the B.R. Wells Rice Research Studies in his memory starting with the 1996 publication. The name of this publication was modified in 2014 to the B.R. Wells Arkansas Rice Research Studies.

FEATURED RICE COLLEAGUE
Rick Cartwright

As a small boy growing up on a small farm near the community of Fifty-Six in Stone County, Rick Cartwright vividly recalls being lowered into a dark cistern with a carbide lamp on his head.

"We had no electricity. No running water inside. No refrigeration," he said. The cistern was "a big hole that we caught the rainwater in for our household needs. Occasionally, my brothers and I had to go down and clean it."

Down among the cave crickets and dead snakes, "It was creepy. We had to load a bucket with stuff I found in there and wash the walls with vinegar," Cartwright said. "We were still in the 19th century."

Those were the days that gave him a keen appreciation for technological advances that most take for granted. Things like toilet paper, for example. Or moon landings.

"When you get introduced to technology in this setting growing up, it makes you pretty interested," he said. "The landing on the moon in July 1969 — that was a big wake up for a lot of my generation. We had the technology to go to another planetary body, and land and return. It got a lot of us interested in technology."

Cartwright never forgot those experiences, and he worked to use the power of technology to improve lives.

Encouraged to attend college by his great-uncle Dean Wallace, an extension forester, Cartwright followed his older brother Mike to Fayetteville. Cartwright credits Dr. James Dale for inspiring an interest in science and plant health, letting him work on phytoplasma and the electron microscope — even though his technique for preparing sections was rough at first.

He earned a Bachelor of Science degree in plant protection/pest management from the University of Arkansas, and after graduation, worked for a short time on an experiment station, where he and his wife, Lynette Warren, lived in a low-cost experimental house. The design was featured nationwide in an Associated Press article as a trend for the future. But the thin construction budget also translated into thin walls, which the young couple found "very interesting" on winter days and nights.

Cartwright then landed a job with the Southern Farmers Association, where new materials and technologies caught his interest.

There, "we were starting to bring in things like first thing woven polypropylene levy gates" at a time when heavy and bulky metal levy gates were de rigeur, he said. "New irrigation technology, harvester parts, the string 'Weedeater,' animal wormers and antibiotics, and early computers were all impressive."

He headed back to Fayetteville for the next step, and under the tutelage of George Templeton, Greg Weidemann, and others in the department of plant pathology, Cartwright's interest in technology deepened and he went on to earn a Master of Science degree. He was then offered a fellowship at the University of California-Davis with Robert Webster, a well-known rice expert. During the years working on his Ph.D. in plant pathology there, he was introduced to the technology of advanced computing, the Global Positioning System, and remote sensing. At the time, researchers were using near-infrared film that could capture signs of stress in plants that were nearly invisible in ordinary light.

"I loved that kind of stuff. You were looking at a world you couldn't see" with the naked eye, Cartwright said.

After returning to Arkansas in 1992 to work with Templeton and Fleet Lee in rice diseases, he worked with county agents, industry field specialists, and other rice scientists to use remote sensing to demonstrate the effectiveness of a new fungicide in rice, later named Quadris.

Since joining the University of Arkansas System Division of Agriculture, Cartwright served in a number of roles, both with the Arkansas Agricultural Experiment Station and the Cooperative Extension Service. As a rice pathologist, his work gained him global renown for his work on major diseases, fungicides, and management of the smuts in rice.

Among the many honors Cartwright earned in his career are the USA Rice Federation Industry Award in 2011 and induction into the Arkansas Agriculture Hall of Fame in 2021.

Never one to stay in a single lane, Cartwright joined forces with agronomists and soil specialists in noting the link between potassium deficiencies and the resurgence of stem rot and brown spot.

Cartwright eventually moved out of the field and into administration. He served as interim head of the plant pathology department and then became associate director-Agriculture and Natural Resources for the Cooperative Extension Service.

In September 2016, Cartwright was appointed interim director of the Cooperative Extension Service, becoming director the following summer. Recalling his days growing up low-tech in Stone County, he urged his colleagues across the extension service to embrace new technologies. With every chance, he pushed for everyone to move the land grant outreach and education into the 21st century. He encouraged "iPads for Agents" early on and heavily invested in virtual technology, which helped during the COVID-19 pandemic. He fostered innovation by creating and staffing a new digital and information technology innovation manager for the extension service. He sought out faculty and funded projects that would continue to push the outward edge of what the extension service was able to do to help Arkansans.

“Over my lifetime, science and technology and discovery have ballooned in importance,” he said. “In my case, we went from 19th century to 21st century very rapidly, and I remain grateful for the experience. This has made me continually optimistic about the present and the future. While many people insist on focusing on negative aspects of life today, I maintain it is the best time to be alive, to be working, and to pursue science and the improvement of mankind.”

“I certainly wish I could start over professionally today, where, as a plant pathologist, instead of telling farmers, ‘well, nothing we can do, just have to try again next year,’ to ‘yes, we know what this is and we can help you’,” Cartwright said. “It is a great feeling to be able to help others, all because of these advancements.”

While science and technology have been great, Cartwright says his career was mainly enhanced by the people he met over the years and one person in particular.

“I know that all things in my life and career were made better by one decision I was fortunate to make in December of 1976, my marriage to Lynette Warren,” he said. “Our relationship has been a blessing and she has made my life and career so rich, and I remain very grateful.”

Mary Hightower
University of Arkansas System Division of Agriculture Communications

FOREWORD

Research reports contained in this publication may represent preliminary or only a single year of results; therefore, these results should not be used as a basis for long-term recommendations.

Several research reports in this publication will appear in other Arkansas Agricultural Experiment Station publications. This duplication is the result of the overlap in research coverage between disciplines and our effort to inform Arkansas rice producers of all the research being conducted with funds from the rice check-off program. This publication also contains research funded by industry, federal, and state agencies.

Use of products and trade names in any of the research reports does not constitute a guarantee or warranty of the products named and does not signify that these products are approved to the exclusion of comparable products.

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The Arkansas Rice Research and Promotion Board

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Trends in Arkansas Rice Production, 2020

J.T. Hardke[1]

Abstract

Arkansas is the leading rice producer in the United States. The state represents 47.5% of total U.S. rice production and 48.1% of the total acres planted to rice in 2020. Rice cultural practices vary across the state and across the U.S. However, these practices are also dynamic and continue to evolve in response to changing political, environmental, and economic times. This survey was initiated in 2002 to monitor and record changes in the way Arkansas rice producers approach their livelihood. The survey was conducted by polling county extension agents in each of the counties in Arkansas that produce rice. Questions included topics such as tillage practices, water sources and irrigation methods, seeding methods, and precision leveling. Information from the University of Arkansas System Division of Agriculture's Degree-Day 50 (DD50) Rice Management Program was included to summarize variety acreage distribution across Arkansas. Other data were obtained from the USDA National Agricultural Statistics Service.

Introduction

Arkansas is the leading rice producer in the United States in terms of acreage planted, acreage harvested, and total production. Each year, rice planting typically ranges from late March into early June, with harvest occurring from late August to early November. Rice production occurs across a wide range of environments in the state. The diverse conditions under which rice is produced lead to variation in the adoption and utilization of different crop management practices. A survey was initiated in 2002 to record annual production practices in order to monitor and better understand changes in rice production practices, including the adoption of new practices. Information obtained through this survey helps to illustrate the long-term evolution of cultural practices for rice production in Arkansas. It also serves to provide information to researchers and extension personnel about the ever-changing challenges facing Arkansas rice producers.

Procedures

A survey has been conducted annually since 2002 by polling county agriculture extension agents in each of the counties in Arkansas that produce rice. Questions were asked concerning topics such as tillage practices, water sources and irrigation methods, seeding methods, and precision leveling. Acreage, yield, and crop progress information was obtained from the USDA National Agricultural Statistics Service (http://www.nass.usda.gov). Rice cultivar distribution was obtained from summaries generated from the University of Arkansas System Division of Agriculture DD50 Rice Management Program enrollment.

Results and Discussion

Rice acreage by county is presented in Table 1 with the distribution of the most widely produced cultivars. RT Gemini 214 CL was the most widely planted cultivar in 2020 at 21.0% of the acreage, followed by RT XP753 (18.8%), Diamond (11.4%), RT 7521 FP (11.2%), RT 7301 (6.4%), CLL15 (4.9%), Jupiter (4.9%), RT CLXL745 (4.7%), RT 7321 FP (3.7%), and Titan (2.7%). Additional cultivars of importance in 2020, though not shown in the table, were PVL01, PVL02, CL153, CL151, CLM04, CL111, RT 7801, and LaKast.

Arkansas planted 1,461,000 acres of rice in 2020, which accounted for 48.1% of the total U.S. rice acres (Table 2). The state-average yield of 7,500 lb/ac (166.7 bu./ac) represented a 20 lb/ac increase compared to 2019. This represented the fourth highest state average yield for Arkansas on record (behind 2013, 2014, and 2018). Frequent rainfall throughout the planting window from March through June resulted in overall delayed planting progress. However, mild conditions throughout the summer and fall seemed responsible for producing favorable rice yields. Dry windows during harvest allowed for improved harvest conditions and overall above-average milling yields as well. Tropical systems, including multiple hurricanes, did impact the rice crop throughout the season, including during harvest, leading to erratic grain yields and millings at times.

Final harvested acreage in 2020 totaled 1,441,000. The total rice produced in Arkansas during 2020 was 108.1 million hundredweight (cwt). This represents 47.5% of the 227.6 million cwt produced in the U.S. during 2020. Over the past three years, Arkansas has been responsible for 46.9% of all rice produced in the U.S. The largest rice-producing counties by acreage in Arkansas during 2020 included Poinsett, Jackson, Lonoke, Arkansas, Cross, and Lawrence, representing 39.3% of the state's total rice acreage (Table 1).

Planting in 2020 fell immediately behind the 5-year average beginning in March due to frequent rainfall events (Fig. 1). Planting progress had reached only 8% by 12 April compared to 28% averaged across the previous five years. Planting progress

[1] Professor, Department of Crop, Soil, and Environmental Sciences, Rice Research and Extension Center, Stuttgart.

continued slowly throughout April, May, and June. As of 3 May, only 48% of acres had been planted compared with an average of 71% by this date across the five previous seasons. By 7 June, 93% of acres had been planted compared to the five-year average of 98%. As harvest began, temperatures remained mild, but the frequency of rainfall events decreased, allowing for improved harvest conditions. By 20 September, harvest progress had reached 44% compared to 63% for the 5-year average (Fig. 2). About 70% of the crop had been harvested by 4 October compared with 86% harvest progress on the same date in previous years. However, it should be noted that many acres harvested from early October and beyond were subjected to major rain and wind events from the remnants of hurricanes that struck the Gulf coast. Harvest progress was complete (100%) by 22 November.

Approximately 53% of the rice produced in Arkansas was planted using conventional tillage methods in 2020 (Table 3). This usually involves fall tillage when the weather cooperates, followed by spring tillage to prepare the seedbed. The remainder of rice acres is planted using stale seedbed (37.7%) or no-till (9.0%) systems. True no-till rice production is not common but is practiced in a few select regions of the state; however, delayed planting due to wet conditions may have led to an increase in no-till acres in 2020. An effort to plant furrow-irrigated rice on the previous year's soybean or corn beds may have also contributed to the increase.

More rice is produced on silt loam soils (50.7%) than any other soil texture (Table 3). Rice production on clay or clay loam soils (25.5% and 20.8%, respectively) has become static over recent years after steadily increasing through 2010. These differences in soil type present unique challenges in rice production, such as tillage practices, seeding rates, fertilizer management, and irrigation.

Rice most commonly follows soybean in rotation, accounting for 67.6% of the rice acreage (Table 3). Approximately 24% of the acreage in 2020 was planted following rice, with the remainder made up of rotation with other crops, including cotton, corn, grain sorghum, wheat, and fallow. The majority of the rice in Arkansas is produced in a dry-seeded, delayed-flood system, with only 3.6% using a water-seeded system. Annually, approximately 85% of all the Arkansas rice acreage is drill-seeded, with the remaining acreage broadcast-seeded (dry-seeded and water-seeded).

Irrigation water is one of the most precious resources for rice producers in Arkansas. Reports of diminishing supplies have prompted many producers to develop reservoir and/or tailwater recovery systems to reduce the "waste" by collecting all available water and re-using it. Simultaneously, producers have tried to implement other conservation techniques to preserve the resource vital to continued production. Groundwater is used to irrigate 77.3% of the rice acreage in Arkansas, with the remaining 22.7% irrigated with surface water obtained from reservoirs or streams and bayous (Table 3).

During the mid-1990s, the University of Arkansas System Division of Agriculture began educating producers on multiple-inlet rice irrigation, which uses poly-tubing as a means of irrigating rice to conserve water and labor. As of 2020, rice farmers utilize this practice on 31.1% of the rice acreage (Table 3). Most remaining acreage is still irrigated with conventional levee and gate systems. Intermittent flooding is another means of irrigation increasing in interest recently as a means to reduce pumping costs and water use, but the practice accounts for only 2.5% of acreage at this time. Additional interest has risen in growing rice in a furrow-irrigated system (row rice) as is common with soybean or corn as a means to simplify crop rotation and management and currently accounts for 16.9% of acreage compared to 10.5% and 7.7% in 2019 and 2018, respectively.

Stubble management is important for preparing fields for the next crop, particularly in rice following rice systems. Several approaches are utilized to manage the rice straw for the next crop, including tillage, burning, rolling, and winter flooding. In 2020, 33.3% of the acreage was burned, 36.8% was tilled, 32.1% was rolled, and 27.9% was winter flooded (Table 3). Combinations of these systems are used in many cases. For example, a significant amount of the acreage that is flooded during the winter for waterfowl will also be rolled. Some practices are inhibited by fall weather, and the wet fall weather from 2018 to 2020 resulted in a decrease in burning and tillage but a subsequent rise in rolling and winter flooding.

Contour levee fields accounted for 49.9% of rice acres in 2020 (Table 3). Precision-leveled, or straight levee, fields represented 37.2% and zero-graded fields 13.3%. Each year growers attempt to make land improvement where possible to improve overall rice crop management, particularly related to water management. Modifying the slope, and subsequently, the levee structure and arrangement in fields can have a profound impact on the efficiency of rice production. Straight levee and zero-grade fields have been shown to significantly reduce water use in rice production in Arkansas.

The use of yield monitors at harvest (79.2%) and grid soil sampling (36.1%) have increased slightly in recent years (Table 3). However, only 25.1% of rice acres are fertilized using variable-rate equipment. Urea stabilizers (products containing NBPT) are currently used on 89.5% of rice acres in Arkansas to limit nitrogen losses due to ammonia volatilization. The use of the Nitrogen Soil Test for Rice (N-STaR) remains low at 7.2% of acres, but additional tools are being developed to improve the confidence and adoption of this practice. In addition, programs such as Pipe Planner, PHAUCET, and MIRI Rice Irrigation were used on 35.9% of rice acres in 2020. The use of a GreenSeeker handheld to monitor in-season nitrogen condition was utilized on 2.8% of acres. The use of cover crops in rice rotations remains limited as wet fall periods in the past few years have limited the implementation of cover crop programs in the state but was a practice used on 1.5% of rice acres during 2020. Harvest aid applications, primarily sodium chlorate, are currently used on 28.9% of acres to improve harvest efficiency.

Pest management is vital to preserving both yield and quality in rice. Foliar fungicide applications were made on 60.3% of rice acres in 2020 (Table 3). Conditions were not as favorable for the development of disease during the 2020 season. Approximately 40% of rice acres received a foliar insecticide application due to rice stink bug infestation levels which were low to moderate overall. Insecticide seed treatments were used on 80.1% of rice acreage as producers continue to utilize this technology each year due to its early-season benefits for both insect control and improved plant growth and vigor.

The use of herbicide-tolerant rice cultivars continues to play a significant role in rice production in Arkansas. The technologies include Clearfield® (tolerant to imidazolinone herbicides), FullPage™ (tolerant to imidazolinone herbicides), and Provisia® (tolerant to ACCase herbicides). Herbicide-tolerant cultivars (all technologies combined) accounted for 39.7% of the total rice acreage in 2020 (Fig. 3). Clearfield acres increased rapidly from 2001 to 2011 but have gradually declined since then. In 2018, Provisia became available on limited acres, and in 2020 was planted on 2.7% of acres. FullPage, similar to Clearfield, was launched in 2020 on 6.4% of acres. Acres of these and other herbicide technologies will likely increase in the coming years. Proper stewardship of these technologies will be the key to their continued success in rice. In areas where stewardship has been poor, imidazolinone-resistant barnyardgrass has been discovered. Evidence of these resistant populations may have served to reduce the number of Clearfield acres by emphasizing the negative effects of improper technology management. In addition, multiple years of this technology and crop rotation have likely cleaned up many red rice fields to the point where they can be safely returned to conventional rice production.

Practical Applications

State average yields over the past 20 years in Arkansas have increased from an average of 129 bu./ac in 1997–1999 to an average of 167 bu./ac in 2018–2020, an increase of 38 bu./acre. This increase can be attributed to the development and adoption of more productive cultivars and improved management practices, including better herbicides, fungicides, and insecticides, improved water management through precision-leveling and multiple-inlet irrigation, improved fertilizer efficiency via timing and the use of urease inhibitors, and increased understanding of other practices such as seeding dates and tillage. Collecting this kind of information regarding rice production practices in Arkansas is important for researchers to understand the adoption of certain practices as well as to understand the challenges and limitations faced by producers in field situations.

Acknowledgments

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Table 1. 2020 Arkansas harvested rice acreage summary.

	Harvested Acreage[a]		Medium-grain			Long-grain								
County	2019	2020	Jupiter	Titan	Others[b]	CLL15	Diamond	RT 7301	RT 7321 FP	RT 7521 FP	RT CLXL745	RT Gemini 214 CL	RT XP753	Others[b]
Arkansas	74,687	88,601	422	1,238	2,779	403	6,126	6,733	3,921	7,544	2,089	22,902	28,520	5,922
Ashley	5,409	12,420	0	0	0	0	0	0	0	0	381	3,049	731	8,259
Chicot	17,880	27,929	0	0	0	7	28	0	0	14,821	7	4,341	6,310	2,417
Clark	1,860	3,764	0	0	0	0	0	0	0	0	683	0	3,081	0
Clay	64,931	75,751	3,553	293	151	5,293	5,930	5,462	4,379	5,933	4,129	12,892	11,929	15,807
Craighead	53,183	60,812	4,590	2,573	823	5,974	5,638	3,549	2,879	4,542	3,009	13,871	8,412	4,952
Crittenden	43,743	58,763	95	5,107	0	0	1,293	8,026	2,841	4,501	549	5,954	28,924	1,474
Cross	71,600	86,464	6,658	3,008	2,313	3,836	11,602	830	2,901	15,272	2,000	24,531	10,031	3,483
Desha	20,399	38,783	0	2,764	0	458	1,255	988	6,360	3,995	1,933	5,165	2,804	13,060
Drew	9,137	16,352	0	0	0	0	0	2,665	1,390	3,427	1,315	3,826	967	2,762
Greene	58,606	61,313	2,577	863	0	3,069	4,789	5,274	1,918	7,106	0	13,770	18,166	3,780
Independenc	5,311	10,977	526	526	0	3,308	0	6,617	0	0	0	0	0	0
Jackson	66,127	98,580	5,300	4,531	1,454	6,701	11,684	12,384	1,898	4,978	2,175	26,531	14,134	6,810
Jefferson	51,730	75,827	1,939	1,410	176	16,953	8,490	80	0	12,038	7,090	5,691	9,119	12,841
Lafayette	3,456	4,030	0	0	0	0	1,539	0	0	0	0	0	2,490	0
Lawrence	76,188	81,514	4,359	8,269	156	2,892	9,499	8,201	1,723	6,220	4,663	7,044	24,097	4,391
Lee	16,670	24,294	816	0	0	768	15,779	615	0	0	0	3,914	1,552	849
Lincoln	17,466	30,177	0	0	0	0	0	1,698	2,463	0	12,447	13,568	0	0
Lonoke	65,728	92,448	3,891	0	0	237	2,264	8,640	2,785	9,547	2,116	34,822	21,461	6,684
Mississippi	56,313	67,237	1,963	0	656	2,389	11,955	5,181	1,923	1,277	1,262	19,375	14,660	6,595
Monroe	39,999	54,818	1,576	1,424	0	4,307	13,523	1,414	0	2,198	600	18,637	6,729	4,410
Phillips	26,920	37,301	726	0	0	0	11,234	10,381	0	2,275	4,608	0	8,077	0
Poinsett	94,753	116,444	20,357	1,710	4,790	7,474	24,820	22	3,102	19,821	6,083	7,080	6,450	14,736
Pope	1,898	4,320	0	0	0	254	0	0	0	0	0	0	0	4,066
Prairie	53,623	58,605	3,235	594	0	2,273	3,179	1,091	6,077	7,961	4,815	15,006	13,403	969
Pulaski	2,894	6,709	453	453	0	0	0	0	0	0	0	5,803	0	0
Randolph	27,582	33,990	4,679	2,730	390	0	0	735	0	6,920	3,568	10,304	4,665	0
St. Francis	34,508	38,979	295	487	694	994	3,655	246	2,916	12,933	1,714	972	13,804	268
White	7,871	6,726	113	0	0	0	2,080	759	774	873	137	1,533	455	0
Woodruff	49,495	52,163	1,718	144	0	1,608	6,007	567	2,641	7,131	0	20,985	7,160	4,201
Others[c]	2,855	9,373	155	0	0	973	1,423	0	0	0	878	1,253	3,418	1,273
Unaccounted[d]	3,179	5,538												3,599
2020 Total		1,441,000	69,997	38,124	14,384	70,173	163,792	92,158	52,891	161,312	68,253	302,820	271,549	135,547
2020 Percent		100.00	4.86	2.65	1.00	4.87	11.37	6.40	3.67	11.19	4.74	21.01	18.84	9.41
2019 Total	1,126,00		106,892	73,490	6,665	715	122,922	0	0	0	108,791	168,302	288,046	250,177
2019 Percent	100.00		9.49	6.53	0.59	0.06	10.92	0.00	0.00	0.00	9.66	14.95	25.58	22.22

[a] Harvested acreage. Source: USDA-NASS, 2021.

[b] Other varieties: PVL01, PVL02, CL153, CL151, CLM04, CL111, RT 7801, LaKast, AB647, ARoma 17, RT CLXP756, RT 7501, CL163, Roy J, Cheniere, CLL16, Jazzman-2, Lynx, Jewel, Jazzman, and Wells.

[c] Other counties: Conway, Faulkner, Franklin, Hot Springs, Little River, Logan, Miller, Perry, and Yell.

[d] Unaccounted for acres is the total difference between USDA-NASS harvested acreage estimate and estimates obtained from each county FSA.

Table 2. Acreage, grain yield, and production of rice in the United States from 2018 to 2020.[a]

State	Area Planted			Area Harvested			Yield			Production		
	2018	2019	2020	2018	2019	2020	2018	2019	2020	2018	2019	2020
	--------------(1,000 ac)--------------			--------------(1,000 ac)--------------			----------------(lb/ac)----------------			-----------------(1,000 cwt[b])-----------------		
AR	1,441	1,161	1,461	1,422	1,126	1,441	7,520	7,480	7,500	106,947	84,257	108,107
CA	506	503	517	504	501	514	8,620	8,460	8,720	43,425	42,362	44,810
LA	440	425	480	436	414	474	7,130	6,380	6,820	31,094	26,408	32,306
MS	140	117	166	139	113	165	7,350	7,350	7,420	10,217	8,302	12,241
MO	224	187	228	220	173	214	7,770	7,370	7,250	17,090	12,747	15,522
TX	195	157	184	189	150	179	7,970	7,350	8,150	15,060	11,028	14,597
US	2,946	2,550	3,036	2,910	2,477	2,987	7,692	7,473	7,619	223,833	185,104	227,583

[a] Source: USDA-NASS, 2021.

[b] cwt = hundredweight.

Table 3. Acreage distribution of selected cultural practices for Arkansas rice production from 2018 to 2020.[a]

	2018		2019		2020	
Cultural Practice	**Acreage**	**% of Total**	**Acreage**	**% of Total**	**Acreage**	**% of Total**
Arkansas Rice Acreage	1,427,000	100.00	1,126,000	100.00	1,441,000	100.00
Soil Texture						
Clay	346,780	24.3	274,537	24.4	368,019	25.5
Clay Loam	304,652	21.3	233,341	20.7	300,045	20.8
Silt Loam	699,065	49.0	568,253	50.5	730,925	50.7
Sandy Loam	59,547	4.2	40,309	3.6	36,171	2.5
Sand	16,957	1.2	9,278	0.8	5,840	0.4
Tillage Practices						
Conventional	720,177	50.5	577,517	51.3	767,392	53.3
Stale Seedbed	616,087	43.2	435,702	38.7	543,562	37.7
No-Till	90,736	6.4	112,500	10.0	219,588	9.0
Crop Rotations						
Soybean	977,377	68.5	760,615	67.6	973,442	67.6
Rice	360,398	25.3	273,153	24.3	344,091	23.9
Cotton	853	0.1	1,727	0.2	2,755	0.2
Corn	49,066	3.4	51,815	4.6	55,566	3.9
Grain Sorghum	1,941	0.1	691	0.1	1,534	0.1
Wheat	1,194	0.1	4,693	0.4	2,344	0.2
Fallow	32,907	2.3	33,025	2.9	61,267	4.3
Other	3,265	0.2	0	0.0	0	0.0
Seeding Methods						
Drill Seeded	1,222,743	85.7	941,872	83.6	1,221,412	84.8
Broadcast Seeded	204,257	14.3	183,846	16.3	167,432	11.6
Water Seeded	65,185	4.6	58,156	5.2	52,156	3.6
Irrigation Water Sources						
Groundwater	1,084,271	76.0	871,110	77.4	1,114,374	77.3
Stream, Rivers, etc.	173,161	11.9	146,662	13.0	142,738	9.9
Reservoirs	169,568	12.1	107,946	9.6	183,887	12.8
Irrigation Methods						
Flood, Levees	804,542	56.4	633,240	56.2	712,463	49.4
Flood, Multiple Inlet	472,225	33.1	342,609	30.4	447,895	31.1
Intermittent (AWD)	39,448	2.8	31,196	2.8	35,873	2.5
Furrow	109,472	7.7	117,991	10.5	244,198	16.9
Sprinkler	31	0.0	682	0.1	571	0.0
Other	0	0.0	0	0.0	0	0.0
Stubble Management						
Burned	394,040	27.6	293,341	26.1	479,299	33.3
Tilled	516,563	36.2	392,884	34.9	530,180	36.8
Rolled	566,202	39.7	423,440	37.6	463,093	32.1
Winter Flooded	388,461	27.2	324,686	28.8	401,457	27.9
Land Management						
Contour levees	684,144	47.9	550,470	48.9	718,765	49.9
Precision-level	560,541	39.3	430,754	38.3	536,209	37.2
Zero-grade	182,315	12.8	144,495	12.8	192,149	13.3
Precision Agriculture						
Yield Monitors	1,060,779	74.3	867,793	77.1	1,141,788	79.2
Grid Sampling	541,455	37.9	426,851	37.9	520,921	36.1
Variable-rate Fertilizer	419,201	29.4	267,024	23.7	361,202	25.1
Use Pipe Planner, Phaucet	410,652	28.8	374,956	33.3	516,898	35.9
Use urea stabilizer (NBPT)	1,154,964	81.1	1,013,281	90.0	1,289,661	89.5
N-STaR	76,609	5.4	68,079	6.0	103,944	7.2
Use GreenSeeker handheld	--	--	42,352	3.8	40,183	2.8
Use Cover Crops	--	--	34,240	3.0	21,362	1.5
Use Sodium Chlorate	--	--	362,652	32.2	417,021	28.9
Pest Management						
Insecticide Seed Treatment	1,054,757	73.9	902,444	80.1	1,153,642	80.1
Fungicide (foliar app.)	808,878	56.7	585,688	52.0	868,717	60.3
Insecticide (foliar app.)	555,505	38.9	546,795	48.6	574,373	39.9

[a] Data generated from surveys of county agriculture extension agents.

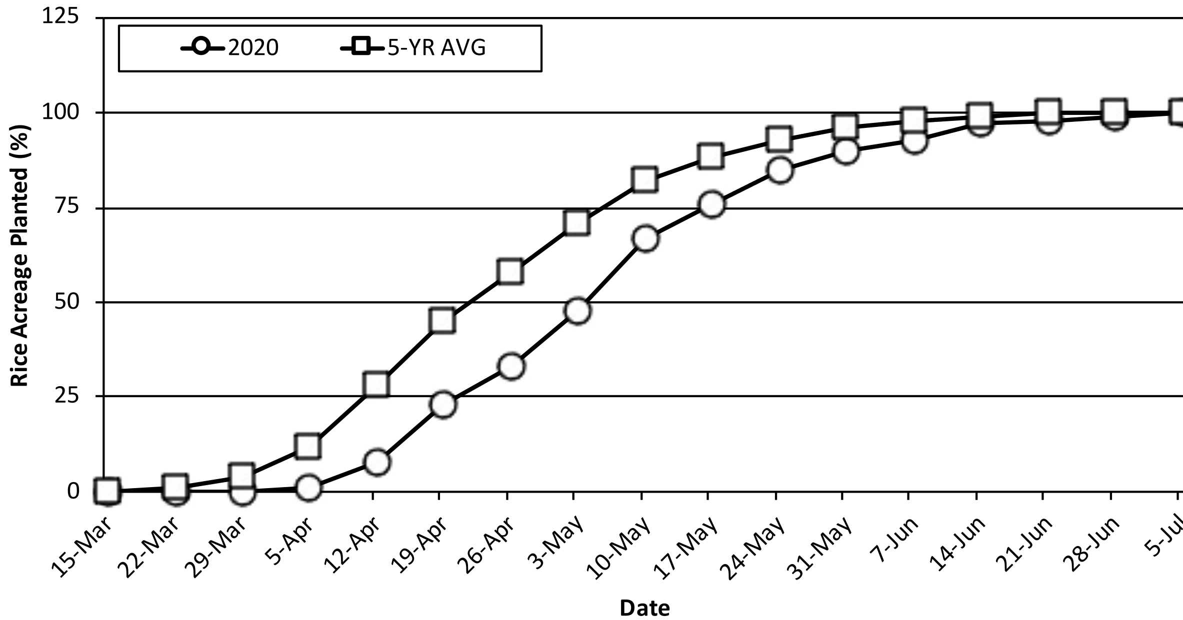

Fig. 1. Arkansas rice planting progress during 2020 compared to the five-year state average (USDA-NASS, 2021).

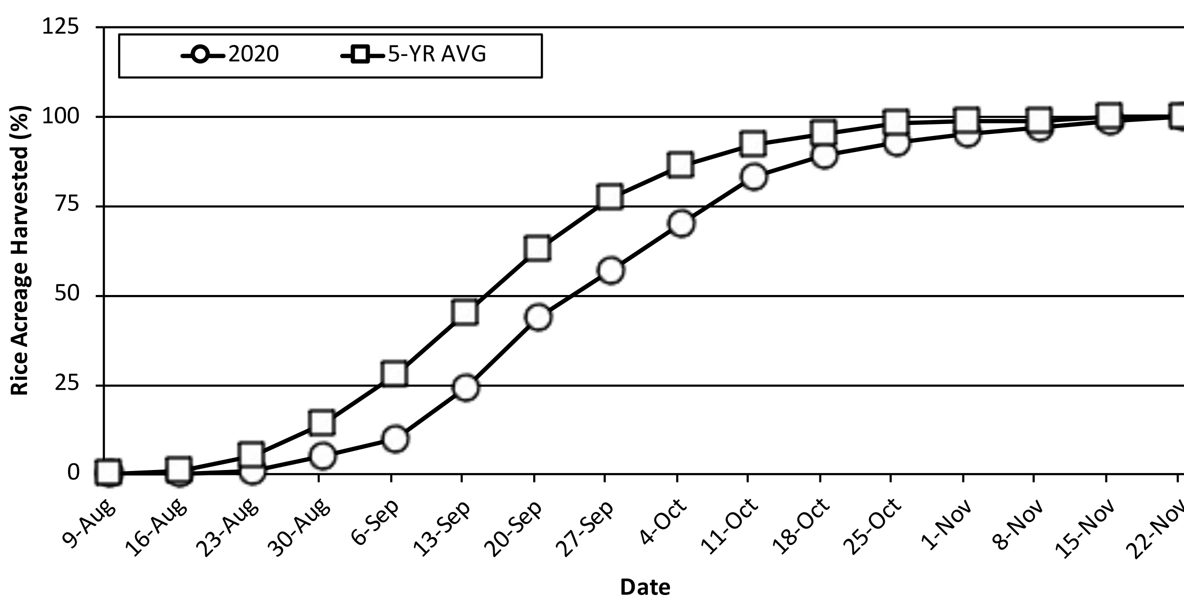

Fig. 2. Arkansas rice harvest progress during 2020 compared to the five-year state average (USDA-NASS, 2021).

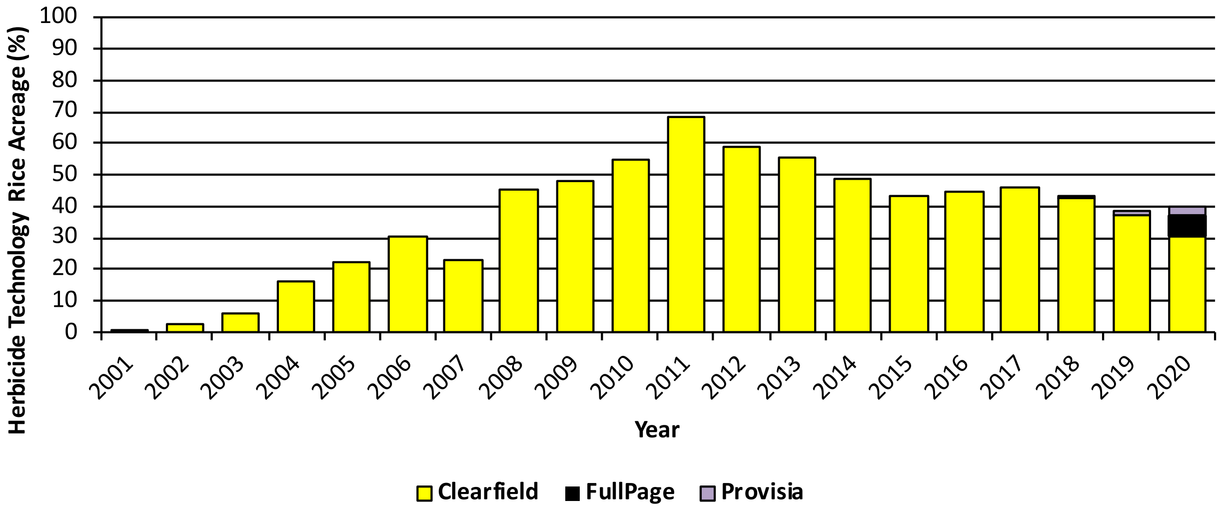

Fig. 3. Percentage of rice planted in Arkansas to rice with herbicide technology including Clearfield, FullPage, and Provisia rice cultivars between 2001 and 2020.

2020 Rice Research Verification Program

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Abstract

The 2020 Rice Research Verification Program (RRVP) was conducted on 9 commercial rice fields across Arkansas. Counties participating in the program included Drew, Jackson, Lawrence, Lee, Lincoln/Jefferson, Lonoke, Monroe, Woodruff, and Mississippi for a total of 661 acres. Grain yield in the 2020 RRVP averaged 187 bu/ac, ranging from 152 to 215 bu/ac. The 2020 RRVP average yield was 20 bu./ac greater than the estimated Arkansas state average of 167 bu./ac. The highest yielding field was the row-rice Jackson County field with a grain yield of 215 bu./ac. The lowest yielding field was in Lee County and produced 152 bu./ac. Milling quality in the RRVP averaged 60/69 (% head rice/% total milled rice).

Introduction

In 1983, the University of Arkansas System Division of Agriculture's Cooperative Extension Service established an interdisciplinary rice educational program that stresses management intensity and integrated pest management to maximize returns. The purpose of the Rice Research Verification Program (RRVP) was to verify the profitability of Cooperative Extension Service (CES) recommendations in fields with less than optimum yields or returns.

The goals of the RRVP are to 1) educate producers on the benefits of utilizing CES recommendations to improve yields and/or net returns, 2) conduct on-farm field trials to verify research-based recommendations, 3) aid researchers in identifying areas of production that require further study, 4) improve or refine existing recommendations which contribute to more profitable production, and 5) incorporate data from RRVP into CES educational programs at the county and state level. Since 1983, the RRVP has been conducted on 501 commercial rice fields in 33 rice-producing counties in Arkansas. Since the program's inception 37 years ago, RRVP yields have averaged 18 bu./ac better than the state average. This increase in yield over the state average can mainly be attributed to intensive cultural management and integrated pest management.

Procedures

The RRVP fields and cooperators are selected prior to the beginning of the growing season. Cooperators agree to pay production expenses, provide expense data, and implement CES recommendations in a timely manner from planting to harvest. A designated county agent from each county assists the RRVP coordinator in collecting data, scouting the field, and maintaining regular contact with the producer. Weekly visits by the coordinator and county agents are made to monitor the growth and development of the crop, to determine what cultural practices need to be implemented, and to monitor the type and level of weed, disease and insect infestation for possible pesticide applications.

An advisory committee, consisting of CES specialists and university researchers with rice responsibility, assists in decision-making, development of recommendations, and program direction. Field inspections by committee members are utilized to assist in fine-tuning recommendations.

Counties participating in the program during 2020 included Drew, Jackson, Lawrence, Lee, Lincoln/Jefferson, Lonoke, Monroe, Woodruff, and Mississippi. The nine rice fields totaled 661 acres enrolled in the program. Six different cultivars were seeded: Diamond (2 fields); RiceTec [RT] XP753 (2 fields); RT 7301 (2 fields); RT 7321 FP (1 field); RT 7521 (1 field) and Horizon Ag CLL15 (1 field). University of Arkansas System Division of Agriculture CES recommendations were used to manage the RRVP fields. Agronomic and pest management decisions were based on field history, soil test results, rice cultivar, and data collected from individual fields during the growing season. An integrated pest management philosophy was utilized based on CES recommendations. Data collected included components such as stand density, weed populations, disease infestation levels, insect populations, rainfall, irrigation amounts, dates for specific growth stages, mid-season nitrogen levels, grain yield, milling yield, and grain quality.

Results and Discussion

Yield

The average RRVP yield was 187 bu./ac with a range of 152 to 215 bu./ac (Table 1). All grain yields of RRVP fields are reported in dry bushels adjusted to 12% moisture. The RRVP average was 20 bu./ac more than the estimated state average yield of 167 bu/ac. Similar yield differences have been observed as the norm since the program began and can be attributed in part to intensive management practices and utilization of CES recommendations. The Jackson County row-rice field, seeded with RT XP753, was the highest yielding RRVP field at 215 bu./ac. Eight of the nine fields enrolled in the program met or exceeded 170 bu./ac. Lee County encountered a late permanent flood (past optimum timing), resulting in the lowest yielding field with Diamond producing 152 bu./ac.

Milling data was recorded on all the RRVP fields. The average milling yield for the nine fields was 60/69 (% head rice/%

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total milled rice). The highest milling yield was 63/69 with RT 7521 FP in Drew County (Table 1). The lowest milling yield was 57/68 with Diamond in Lee County. The milling yield of 55/70 is considered the standard used by the rice milling industry.

Planting and Emergence

Planting began with Jackson County on 17 April and ended with Monroe County on 21 May (Table 1). Four of the verification fields were planted in April and five in May. An average of 78 lb of seed/ac was planted for pure-line varieties and 24 lb seed/ac for hybrids. Seeding rates were determined with the CES RICESEED program for all fields. An average of 30 days was required for emergence. Stand density averaged 18 plants/ft² for pure-line varieties and 7 plants/ft² for hybrids. The seeding rates in some fields were slightly higher than average due to soil texture and planting date. Clay soils generally require an elevated seeding rate to achieve desired plant populations.

Fertilization

The Nitrogen Soil Test for Rice (N-STaR) was utilized for seven RRVP fields and reduced the total nitrogen (N) recommendation by an average of 15 lb N/ac when compared with the standard N recommendation. However, row-rice fields call for additional N in 3 fields during the season. The recommendations prompting the N additions are described in the field reviews and the amounts are included in Table 2.

As with standard N recommendations for rice, N-STaR N recommendations consider a combination of factors, including soil texture, previous crop, and cultivar requirements (Tables 1 and 2). The GreenSeeker hand-held crop sensor was used at least weekly in all fields after panicle initiation through late boot stage to verify that N levels were adequate for the targeted yield potential.

Phosphorus (P), potassium (K), and zinc (Zn) fertilizer were applied based on soil test analysis recommendations (Table 2). Phosphorus was applied pre-plant to Drew, Jackson, Lawrence, Lincoln/Jefferson, Mississippi, and Monroe County fields. Potassium was applied to Lawrence, Lee, Lonoke, Monroe, and Woodruff County fields. Zinc was applied as a pre-plant fertilizer to fields in Lee, Lincoln/Jefferson, Mississippi, and Woodruff Counties. For Monroe, Randolph, White, and Woodruff Counties, zinc seed treatment was used with all hybrid rice cultivars at a rate of 0.5 lb Zn/100 lb seed. The average per-acre cost of fertilizer across all fields was $110.95.

Weed Control

Clomazone (Command) herbicide was utilized as either a stand-alone, premix, or tank mix application in all 9 program fields for early-season grass control (Table 3). Quinclorac (Facet) was utilized in 6 of 9 fields, again, as either a stand-alone, premix, or tank mix application for both pre-emergence and early post-emergence treatments. Overlapping residuals proved to be an effective strategy utilized in all 9 fields. All 9 fields utilized a combination of both grass and broadleaf residual herbicides. Three fields (Drew, Lawrence, and Mississippi Counties) were seeded in imidazolinone (IMI) tolerant cultivars, either Clearfield or FullPage technologies (Table 1).

Disease Control

A foliar fungicide was applied in 5 of the 9 program fields (Lawrence, Lincoln/Jefferson, Mississippi, Monroe and Woodruff Counties). These were preventive treatments applied for kernel smut and false smut diseases (Table 4). Generally, fungicide rates are determined based on the cultivar, growth stage, climate, disease incidence/severity, and disease history. However, preventative treatments for kernel or false smut and rice blast require specific rates depending on the product used. Nine fields had a seed treatment containing a fungicide.

Insect Control

One field (Monroe County) was treated with a foliar insecticide application for rice stink bug (Table 4). Eight other fields received an insecticide seed treatment.

Irrigation

Well water was used exclusively for irrigation in all nine of the fields in the 2020 RRVP. Three fields (Drew, Jackson and Jefferson/Lincoln) were grown under furrow irrigated rice (FIR; row rice) management. Multiple Inlet Rice Irrigation (MIRI) was utilized in the six conventionally flooded fields. Typically, a 25% reduction in water use is observed when using MIRI, which employs polytube irrigation and a computer program to determine the size of tubing required, as well as the correct number and size of holes punched into it to achieve uniform flood-up across the field. Flow meters were used in six fields to record water usage throughout the growing season (Table 5). In three fields where flow meters for various reasons could not be utilized, the average across all irrigation methods (30 inches) was used. The difference in irrigation water used was due in part to rainfall amounts which ranged from a low of 9.7 inches to a high of 20.9 inches.

Economic Analysis

This section provides information on production costs and returns for the 2020 Rice Research Verification Program (RRVP). Records of field operations on each field provided the basis for estimating production costs. The field records were compiled by the RRVP coordinators, county Extension agents, and cooperators. Production data from the 9 fields were applied to determine costs and returns above operating costs, as well as total specified costs. Operating costs and total costs per bushel indicate the commodity price needed to meet each cost type.

Operating costs are those expenditures that would generally require annual cash outlays and would be included in an annual operating loan application. Actual quantities of all operating inputs as reported by the cooperators are used in this analysis. Input prices are determined by data from the 2020 Crop Enterprise Budgets published by the Cooperative Extension Service and information provided by the cooperating producers. Fuel and repair costs for machinery are calculated using a budget calculator based on parameters and standards established by the American Society of Agricultural and Biological Engineers. Machinery repair costs should be regarded as estimated values for full-service repairs, and actual cash outlays could differ as producers provide unpaid labor for equipment maintenance.

Fixed costs of machinery are determined by a capital recovery method which determines the amount of money that should be set aside each year to replace the value of equipment used in production. Machinery costs are estimated by applying engineering formulas to representative prices of new equipment. This measure differs from typical depreciation methods, as well as actual annual cash expenses for machinery.

Operating costs, fixed costs, costs per bushel, and returns above operating and total specified costs are presented in Table 6. Costs in this report do not include land costs, management, or other expenses and fees not associated with production. Operating costs ranged from \$436.13/ac for Lee County to \$744.77/ac for Drew County, while operating costs per bushel ranged from \$2.56/bu. for Jackson County to \$4.05/bu. for Drew County. Total costs per acre (operating plus fixed) ranged from \$340.53/ac for Drew County to \$720.53/ac for Jackson County, and total costs per bushel ranged from \$3.11/bu. for Jackson County to \$4.49/bu. for Drew County. Returns above operating costs ranged from \$340.53/ac for Drew County to \$720.53/ac for Jackson County, and returns above total costs ranged from \$258.86/ac for Drew County to \$600.40/ac for Jackson County.

A summary of yield, rice price, revenues, and expenses by expense type for each RRVP field is presented in Table 7. The average rice yield for the 2020 RRVP was 187 bushels/ac but ranged from 152 bu./ac for Lee County to 215 bu./ac for Jackson County. An Arkansas average long-grain cash price of \$5.01/bu. was estimated using USDA, National Agricultural Statistics Service (NASS) U.S. long-grain price data for the months of August through October. The RRVP had all fields planted to long-grain rice. A premium or discount was given to each field based on the milling yield observed for each field and a standard milling yield of 55/70 for long-grain rice. Broken rice was assumed to have 65% of whole-grain price value. If milling yield was higher than the standard, a premium was made; while a discount was given for milling less than the standard. Estimated long-grain prices adjusted for milling yield varied from \$5.74/bu. in Lee County to \$5.94/bu. in Mississippi County (Table 7).

The average operating expense for the 9 RRVP fields was \$594.77/ac (Table 7). Fertilizers & nutrients expenses accounted for the largest share of operating expenses on average (19.6%) followed by post-harvest expenses (18.9%), seed (18.7%), and chemicals (12.7%). Although seed's share of operating expenses was 18.7% across the 9 fields, its average cost and share of operating expenses varied depending on whether a Clearfield hybrid was used (\$135.87/ac; 26.2% of operating expenses), a non-Clearfield hybrid was used (\$149.28/ac; 23.6% of operating expenses), or a non-Clearfield non-hybrid (pure-line) variety was used (\$36.38/ac; 7.9% of operating expenses). One of the 9 RRVP fields in 2020 planted a Clearfield non-hybrid (pure-line) variety.

The average return above operating expenses for the 9 fields was \$399.30/ac and ranged from \$240.53/ac for Drew County to \$720.53/ac for Jefferson County. The average return above total specified expenses for the 9 fields was \$322.86/ac and ranged from \$277.95/ac for Monroe County to \$600.40/ac for Mississippi County. Table 8 provides select variable input costs for each field and includes a further breakdown of chemical costs into herbicides, insecticides, and fungicides. Table 8 also lists the specific rice cultivars grown on each RRVP field.

Field Summaries

Drew County

The Drew County furrow-irrigated rice (FIR) field was located just west of Tiller on Perry Clay soil. The field consisted of 40 acres, and the previous crop grown was soybean. The cultivar chosen was RT 7521 FP treated with the company's standard seed treatment. The field was drill-seeded at 23 lb/ac on 4 May. Emergence was observed on 18 May with a stand count of 7.1 plants/ft^2. No tillage practices were used for spring field preparation. According to the soil test, 18-46-0 lb/ac (N-P_2O_5-K_2O) was applied along with 50 lb/ac ammonium sulfate. Glyphosate, Command, and Sharpen herbicides were applied at planting on 4 May. Preface, Facet, and Prowl H_2O were applied as post-emergence herbicides on 22 May. Command and Preface herbicides were applied on 4 June followed by Regiment and Preface applied 18 June. N-STaR (Nitrogen Soil Test for Rice) was utilized on the field. Nitrogen in the form of urea plus an approved NBPT was applied at 165 lb/ac on 3 June followed by 165 lb/ac on 18 June. Two more applications were made with 100 lb/ac on 24 June, followed by 65 lb/ac on 25 July. Using Trimble GreenSeeker, the N response levels remained adequate throughout the season. Intermittent flushing was utilized for irrigation. Sheath blight disease was prevalent on the upper end of the field yet never reached threshold levels. Rice stink bug numbers remained low and did not require treatment. The field was harvested on 12 September, yielding 184 bu./ac and a milling yield of 63/69. The average harvest moisture was 16%. Total irrigation was 30 ac-in./ac, and total rainfall was 17.5 inches.

Jackson County

The precision-graded furrow-irrigated rice (FIR) field was located 2 miles west of Newport on Amagon, Forestdale, and Dexter silt loam soils. The field was 140 acres, and the previous crop grown was soybean. A hipper was used prior to drill-seeding on April 17 at a seeding rate of 25 lb/ac. The cultivar was RT XP753 with the company's standard seed treatment. A pre-emergence application of Command herbicide plus glyphosate for burndown was applied at planting. Rice emergence was observed on May 5 with a stand count of 6.7 plants/ft^2. A post-emergence tank mix application of Prize (quinclorac), Prowl H_2O, and Command was made on 10 May, followed by Command on 15 May. Loyant herbicide was applied on part of the field (40 acres) for pigweed control on 1 June, followed by a 2,4-D amine application on 16 June. N fertilizer in the form of urea plus an approved NBPT product was applied preflood on 8 June at 160 lb/ac following the N-STaR recommendation. The second N application was made 20 June at 160 lb/ac. The third N application was made on 26 June at 100 lb/ac. The late-boot N application was made on 16 July at 65 lb/ac. Intermittent flushing was utilized for water management. The field never reached treatment level for disease or stink bugs. The rice was harvested on 13 September, yielding 215 bu./ac. The milling yield was 62/70. The average harvest moisture was 18%. Total irrigation for the season was 30.5 ac-in./ac. Rainfall was 19.05 in.

Lawrence County

The Lawrence County field was located northwest of Hoxie on Foley-Calhoun complex and McCrory fine sandy loam soil. The field was 35 acres, and the previous crop grown was soybean. No spring conventional tillage practices were used for field preparation, and a pre-plant fertilizer based on soil test analysis was applied on 20 April at 0-50-90 lb/ac (N-P_2O_5-K_2O). Prior to planting Roundup PowerMaxx was applied for burndown. On 30 April, CLL15 treated with CruiserMaxx Rice, zinc, and Release was drill-seeded at 80 lb/ac. Pre-emergence herbicides Command, Bolero, and Prowl H_2O were applied on 26 April. Rice emergence was observed on 5 May at 19 plants/ft^2. Newpath herbicide was applied on 30 May. Regiment herbicide was applied for grass escapes with a MudMaster trimming the field (10 acres). The levees were sprayed with Stam, Facet, Loyant, and Permit herbicides. Using the N-STaR recommendation, urea plus an approved NBPT product was applied preflood at a rate of 260 lb/ac. The permanent flood was established within 4 days utilizing multiple-inlet rice irrigation (MIRI). Flood levels were adequately maintained throughout the growing season. Trimble GreenSeeker technology was utilized prior to midseason growth stages to monitor N levels. Midseason N in the form of urea was applied 2 July at 100 lb/ac. Propiconazole fungicide was applied on 20 July as a kernel smut prevention treatment. The field was harvested on 16 September, yielding 170 bu./ac and a milling yield of 61/68. The average field moisture was 17%. The total irrigation was 30 ac-in./ac, and total rainfall was 5.25 in.

Lee County

The 97-acre field was located just west of Moro on Henry silt loam soil. Soybean was the previous crop grown on the field. Conventional tillage practices were performed on the contour-levee field. A pre-plant fertilizer blend of 0-50-90-10 lb/ac (N-P_2O_5-K_2O-Zn) was applied according to the soil sample analysis. The variety Diamond treated with CruiserMaxx Rice seed treatment was drill-seeded at 80 lb/ac on 7 May. Command and Gambit herbicides were applied on 19 May as pre-emergence herbicides. Emergence was observed on 18 May with 20 plants/ft^2. Sharpen and Permit Plus were applied on 3 June as a post-emergence herbicide application. Based on N-STaR recommendations, N fertilizer in the form of urea plus an approved NBPT product was applied at 210 lb/ac on 18 June. The permanent flood was delayed past optimum timing due to levee gate installation. Based on the GreenSeeker response index midseason N fertilizer was applied at 100 lb/ac on 5 July. The field did not reach treatment levels for disease or stink bugs. The field was harvested on 29 September with a disappointing yield of 152 bu./ac and a milling yield of 57/68. The average harvest moisture was 12%. Total irrigation was 28 ac-in./ac, and total rainfall was 10.4 in.

Lincoln/Jefferson County

The 48-acre no-till furrow-irrigated rice (FIR) field was located just west of Pine Bluff on Sharkey clay soil. The previous crop was soybean. According to the soil test, a pre-plant fertilizer of 12-40-0-10-1 lb/ac (N-P_2O_5-K_2O-Zn-S) was applied prior to planting. The cultivar RT 7301, treated with the company's standard seed treatment, was drill-seeded on 7 May. The seeding rate was 23 lb/ac. Glyphosate, Command, and Gambit herbicides were applied at planting. The rice emerged on 28 May with 6 plants/ft^2. RiceBeaux and Facet L were applied as post-emergence herbicides on June 4. N fertilizer in the form of urea with an approved NBPT product was applied at 170 lb/ac on 20 June following the N-STaR recommendation. The second N application was made on 3 July at 170 lb/ac. The third N application was made on 10 July at 100 lb/ac. The late-boot N application was made on 25 July at 65 lb/ac. Based on GreenSeeker response index during midseason growth stages, N levels were adequate. The field was treated for kernel smut prevention with the fungicide propiconazole on 23 July. The field was harvested late on 13 November, yielding 183 bu./ac with a milling yield of 61/68. The average harvest moisture was 15%. Total irrigation water use was 28 ac-in./ac, and total rainfall was 19.05 in.

Lonoke County

The 42-acre contour field was located north of Lonoke on a Callaway silt loam soil. Spring conventional tillage practices were utilized, and pre-plant fertilizer was applied at 0-0-60 lb/ac (N-P_2O_5-K_2O) according to the soil test. Glyphosate herbicide was used as a burndown on 20 March. Glyphosate and Command were applied as a burndown and pre-emergence herbicide on 16 April. The cultivar RT 7301 treated with the company's standard seed treatment was drill-seeded at 22 lb/ac on 16 April. Stand emergence was observed on 15 May with 5.4 plants/ft^2. Stam, Facet L, Prowl H_2O, and Permit were applied as post-emergence herbicides on 14 May. Nitrogen fertilizer in the form of urea plus NBPT was applied on 18 May according to the N-STaR recommendation. Multiple-inlet rice irrigation (MIRI) was utilized to achieve a more efficient permanent flood. Based on GreenSeeker response index during midseason growth stages, N levels were adequate. The late-boot N fertilizer application was made on 1 July at 65 lb/ac. The field was harvested on 12 September yielding, 201 bu./ac and a milling yield of 61/71. Total irrigation water use was 11.5 ac-in./ac, and total rainfall was 14.25 in.

Mississippi County

The precision-graded Mississippi County field was located just north of Keiser on a Sharkey silty clay complex soil. Conventional tillage practices were used for field preparation in the spring. Based on soil test analysis, pre-plant fertilizer was applied at 0-40-0-10 lb/ac (N-P_2O_5-K_2O-Zn). On 18 April, RT 7321 FP treated with the company's standard seed treatment was drill-seeded at 29 lb/ac. Command and glyphosate were applied on 18 April as pre-emergence and burndown herbicides. Stand emergence was observed on 6 May with 7.5 plants/ft^2. Preface and Prowl H_2O herbicides were applied on 18 May. Loyant herbicide was applied on levees for pigweed control on 20 May. Using the N-STaR recommendation, N in the form of urea plus an approved NBPT product was applied at 300 lb/ac. The late-boot urea application of 70 lb/ac was made on 12 July. Propiconazole fungicide was applied on 14 July for smut prevention. The field was harvested 8 September yielding 210 bu./ac with a milling yield of 62/71. The harvest moisture was 12%. Total irrigation use was 30 ac-in./ac, and rainfall totaled 9.65 in.

Monroe County

The 145-acre contour field was located west of Monroe. The soil classification was Dundee and Foley Calhoun Bonn. Spring conventional tillage practices were used for field preparation, and based on soil analysis, a 0-45-60 lb/ac ($N-P_2O_5-K_2O$) was applied 18 May. The cultivar RT XP753 treated with the company's standard seed treatment was drill-seeded at 22 lb/ac on 21 April. Glyphosate and Command herbicides were applied at planting. Emergence was observed on 27 May with 6.4 plants/ft^2. Regiment, Facet L, and Permit Plus were applied as post-emergence herbicides on 10 June. Duet and Permit herbicides were applied 8 July. Regiment and Facet L herbicides were applied to the levees using a Bowman MudMaster on 8 July. Using the N-STaR recommendation, N fertilizer in the form of urea was applied at 270 lb/ac on 11 June. Based on GreenSeeker response index during midseason growth stages, N levels were adequate. Late-boot N fertilizer was applied as urea at 65 lb/ac on 22 July. Propiconazole fungicide was applied as smut prevention on 16 July. Stink bugs reached threshold levels, and lambda-cyhalothrin was applied on 16 September. The field was harvested on 3 October yielding 188 bu./ac. The milling yield was 57/70, and the average harvest moisture was 15%. Total irrigation for the season was 30 ac-in./ac, and total rainfall was 13.35 in.

Woodruff County

The precision-graded Woodruff County field was located 3 miles south of McCrory on Wiville fine sandy loam and Tuckerman loam soils. The field was 46 acres, and the previous crop grown was soybean. Spring conventional tillage practices were used for field preparation, and a pre-plant fertilizer based on soil test analysis was applied at 0-0-90-3 lb/ac ($N-P_2O_5-K_2O-Zn$). On 3 May, the cultivar Diamond with Apron, Maxim, and zinc seed treatments was drill-seeded at 73 lb/ac. Command herbicide was applied pre-emergence on 4 May. Rice emergence was observed on 14 May with a stand count of 16 plants/ft^2. A post-emergence application of Regiment, Facet L, and Permit herbicides was made on 29 May. On 30 May, the N-STaR recommendation of 240 lb/ac of urea plus an approved NBPT product was made. Flood-up occurred over the next 4 days using the multiple-inlet rice irrigation (MIRI) system. GreenSeeker technology was utilized during midseason growth stages to monitor the crop's N level. The planned midseason N application was made with urea at 100 lb/ac on 7 July. On 22 July, propiconazole fungicide was applied for false smut prevention. The field was harvested on 21 September yielding 180 bu./ac. Moisture at harvest was 17%. The milling yield was 57/69. Total irrigation was 41.7 ac-in./ac and total rainfall for the season was 15.8 in.

Practical Applications

Data collected from the 2020 RRVP reflects the continued general trend of improved rice yields and returns. Analysis of this data showed that the average yield was significantly higher in the RRVP compared to the state average, and the cost of production was equal to or less than the Cooperative Extension Service-estimated rice production costs.

Acknowledgments

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Table 1. Agronomic information for fields enrolled in the 2020 Rice Research Verification Program.

Field location by county	Cultivar	Field size	Previous crop	Seeding rate	Stand density	Planting date	Emergence date	Harvest date	Yield	Milling yield [a]	Harvest moisture
		ac		lb/ac	plants/ft^2				bu./ac	%HR/%TR	%
Drew	RT 7521 FP	40	Soybean	23	7	4-May	18-May	12-Sept	184	63/69	16
Jackson	RT XP753	140	Soybean	25	7	17-Apr	5-May	13-Sept	215	62/70	18
Lawrence	CLL15	35	Soybean	80	19	30-Apr	5-May	16-Sep	170	61/68	17
Lee	Diamond	97	Soybean	80	20	7-May	18-May	29-Sep	152	61/70	12
Lincoln/Jefferson	RT 7301	48	Soybean	23	6	7-May	28-May	13-Nov	183	61/68	12
Lonoke	RT 7301	42	Soybean	22	6	16-Apr	15-May	12-Sep	201	61/71	15
Mississippi	RT 7321 FP	68	Soybean	29	8	18-Apr	6-Mayr	8-Sept	210	62/71	12
Monroe	RT XP753	145	Fallow	22	6	21-May	27-May	3-Oct	188	57/70	15
Woodruff	Diamond	46	Soybean	73	16	3-May	14-May	21-Sept	180	57/69	17
Average		**73**	------	[b]	[c]	**14-May**	**15-May**	**14-Sep**	**187**	**60/69**	**15**

[a] Milling yield numbers: First number = % Head rice (whole white grains)/Second number = % Total white rice (whole grains + broken grains).
[b] Seeding rates averaged 78 lb/ac for conventional cultivars and 24 lb/ac for hybrid cultivars.
[c] Stand density averaged 18 plants/ft^2 for conventional cultivars and 7 plants/ft^2 for hybrid cultivars.

Table 2. Soil test results, fertilization, and soil classification for fields enrolled in the 2020 Rice Research Verification Program.

		Soil test			Applied fertilizer			
Field location by county	pH	P	K	Zn	Mixed fertilizer[a] N-P-K-Zn[b]	N-STaR urea (46%N) rates and timing [c, d]	Total N rate [e]	Soil classification
		------------(lb/ac)	-------------		---------------------(lb/ac)	--------------------	(lb N/ac)	
Drew	6.0	29	535	4.2	18-46-0-0	165-165-100-65	228[e]	Perry clay
Jackson	6.4	64	259	15.4	18-46-0-0	160-160-100-65	123[e]	Amagon & Foresdale silt loam
Lawrence	7.0	36	220	39.6	0-50-90-0	260-100-0	166	Jackport silty clay
Lee	7.4	55	182	3.9	0-50-90-10	210-100	143	Henry silt loam
Lincoln/Jefferson	6.8	19	756	5.9	12-40-0-10	170-170-100-65	232[e]	Perry Clay
Lonoke	6.3	68	258	4.2	0-0-60-0	260-65-0	150	Calloway silt loam
Mississippi	7.3	43	364	7.8	12-40-0-10	300-70-0	103	Sharkey-Steel silty clay
Monroe	6,8	44	247	3.9	0-45-60-0	270-0-65-1	103	Foley Calhoun Bonn Dundee
Woodruff	6.1	60	165	5.6	0-0-90-3	240-100-0	156	Wiville fine sandy loam

[a] Column represents regular pre-plant applications.
[b] N = nitrogen, P = phosphorus, K = potassium, Zn = zinc.
[c] Timing: preflood – midseason – boot. Each field was fertilized according to its N-STaR recommendation. The mark (*) denotes an adjusted N-STaR rate and timing for furrow irrigated rice.
[d] N-STaR preflood N recommendation in all fields was treated with an approved NBPT product to minimize N loss due to ammonia volatilization.
[e] Row rice fields received additional seasonal N exceeding the N-STaR recommendation by 46 lb.

Table 3. Herbicide rates and timings for fields enrolled in the 2020 Rice Research Verification Program.

Field location by county	Pre-emergence herbicide applications	Post-emergence herbicide applications
	(trade name and product rate/ac)[a]	
Drew	Glyphosate (1 qt) + Command (16 oz) + Sharpen (2 oz)	Preface + Facet L (252 oz) + Prowl (2.1 pt) FB Command (18 oz) + Preface (6 oz) NIS (16 oz) FB Regiment (0.63) + Preface (6 oz) + Triple Play (16 oz)
Jackson	Command (12.8 oz) + Glyphosate (32 oz)	Prize/Quinclorac (12.8 oz) + Prowl H_2O (2.1 pt) + Command (6 oz) FB Command (6 oz) FB Loyant spot treatment (8 oz)
Lawrence	Roundup Power Maxx (1 qt)	Command (12.8 oz) + Bolero (2 pt) + Prowl H_2O (2.1 pt) FB Regiment (0.5 oz) + Triple play Trim Only (12.8 oz)
Lee	Glyphosate (40 oz) + FirstShot (0.5 oz)	Command (12.8 oz) + Gambit (1 oz) FB Sharpen (1 oz) + Permit Plus (0.75 oz) + COC (1 pt)
Lincoln/Jefferson	Glyphosate (32 oz) + Command (16 oz) + Gambit (1.5 oz)	Rice Beaux (4 qt) + Facet L (1 qt)
Lonoke	Glyphosate (42 oz) FB Glyphosate (42 oz) + Command (1 pt)	Stam (1 qt) + Facet L (1 qt) + Permit (1 oz) + Prowl H_2O (2.1 pt)
Mississippi	Glyphosate (40 oz) + Command (20 oz)	Preface (4oz) + Prowl H_2O (2.1 pt) FB Loyant Levees Only (10 oz)
Monroe	Glyphosate (32 oz) + Command (16 oz)	Regiment (0.4 oz) + Facet L (32 oz) + Permit Plus (0.75 oz) + Triple Play (12.8 oz)
Woodruff	Command (16 oz)	Regiment (0.4 oz) + Facet L (32 oz) + Permit (1 oz) + Triple Play (16 oz)

[a] FB = followed by and is used to separate herbicide application events; COC = Crop Oil Concentrate; MSO = methylated seed oil.

Table 4. Seed treatments, foliar fungicide, and insecticide applications made in the 2020 Rice Research Verification Program.

	Seed treatments	Foliar fungicide and insecticide applications			
Field location by county	Fungicide and/or insecticide seed treatment for control of diseases and insects of seedling rice[a]	Fungicide applications for control of sheath blight/kernel smut/false smut	Fungicide applications for control of rice blast	Insecticide applications for control of rice water weevil	Insecticide applications for control of rice stink bug/chinch bug
	(Product trade name and rate/cwt seed)	-------------------------------- (Product trade name and rate/ac)--------------------------------			
Drew	RTST	------	------	------	------
Jackson	RTST	------	------	------	------
Lawrence	CruiserMaxx Rice (7 fl oz) + Zinc + Release	Propiconazole (6 oz)	------	------	------
Lee	CruiserMaxx Rice (7 oz)	------	------	------	------
Lincoln/Jefferson	RTST	Propiconazole (6 oz)	------	------	------
Lonoke	RTST	------	------	------	------
Mississippi	RTST	Propiconazole (6 oz)	------	------	------
Monroe	RTST	Propiconazole (6 oz)	------	------	Lambda-Cyhalothrin (2.1 oz)
Woodruff	Zinc, Apron XL LS (0.64 oz/cwt) Maxim 4 FS (0.8 oz cwt)	Propiconazole (6 oz)	------	------	------

[a] RTST = RiceTec Seed Treatment. This abbreviation defines those fields with seed treated by RiceTec, Inc. prior to seed purchase. RTST seed is treated with zinc compounds intended to enhance germination and early-season plant growth.

Table 5. Rainfall and irrigation information for fields enrolled in the 2020 Rice Research Verification Program.

Field location by county	Rainfall	Irrigation[a]	Rainfall + Irrigation
	(in.)	(ac-in.)	(in.)
Drew	17.5	26.0	43.5
Jackson	19.5	30.5	50.0
Lawrence	5.3	28.0	33.3
Lee	10.4	30.0*	40.4
Lincoln/Jefferson	20.9	26.0	46.9
Lonoke	14.3	11.5	25.8
Mississippi	9.7	30.0*	39.7
Monroe	13.4	30.0*	43.4
Woodruff	15.9	41.7	57.6

[a] Not all fields were equipped with flow meters to monitor water use for irrigation. Therefore, the historical average irrigation amount in fields with flow meters was used for fields with no irrigation data. Irrigation amounts using this calculated average are followed by an asterisk (*).

Table 6. Operating Costs, Total Costs, and Returns for fields enrolled in the 2020 Rice Research Verification Program.

County	Operating costs	Operating costs	Returns to operating costs	Fixed costs	Total costs	Returns to total costs	Total costs
	($/ac)	($/bu.)	($/ac)	($/ac)	($/ac)	($/ac)	($/bu.)
Drew	744.77	4.05	340.53	81.67	826.44	258.86	4.49
Jackson	549.36	2.56	720.53	120.13	669.49	600.40	3.11
Lawrence	533.89	3.14	456.79	97.44	631.33	359.34	3.71
Lee	436.13	2.87	436.92	106.25	542.39	330.67	3.57
Lincoln/Jefferson	667.14	3.65	399.30	76.43	743.57	322.86	4.06
Lonoke	549.60	2.73	639.23	95.77	645.37	543.46	3.21
Mississippi	683.84	3.26	562.61	113.98	797.82	448.63	3.80
Monroe	697.29	3.71	393.46	115.51	812.80	277.95	4.32
Woodruff	490.88	2.72	548.23	108.22	599.11	440.00	3.33
Average	**594.77**	**3.19**	**499.73**	**101.71**	**696.48**	**398.01**	**3.73**

Table 7. Summary of Revenue and Expenses per Acre for fields enrolled in the 2020 Rice Research Verification Program.

Receipts	Drew	Jackson	Lawrence	Lee	Lincoln-Jefferson
Yield (bu.)	184	215	170	152	183
Price Received	5.90	5.91	5.83	5.74	5.83
Total Crop Revenue	**1085.30**	**1269.89**	**990.68**	**873.06**	**1066.43**
Operating Expenses					
Seed	163.53	155.50	109.65	43.35	140.07
Fertilizers and Nutrients	141.09	101.47	106.87	105.90	146.04
Chemicals	173.37	58.25	83.79	61.21	118.74
Custom Applications	66.40	8.00	36.80	32.80	67.20
Diesel Fuel	13.36	15.18	13.65	17.47	12.03
Repairs and Maintenance	18.79	23.06	19.60	21.32	17.94
Irrigation Energy Costs	34.25	40.18	36.88	39.52	34.25
Labor, Field Activities	5.98	6.76	7.31	8.42	5.53
Other Inputs & Fees, Pre-harvest	16.96	11.23	16.74	14.42	14.90
Post-harvest Expenses	111.04	129.75	102.60	91.73	110.44
Total Operating Expenses	**744.77**	**549.36**	**533.89**	**436.13**	**667.14**
Returns to Operating Expenses	**446.06**	**360.73**	**351.67**	**459.98**	**278.56**
Capital Recovery and Fixed Costs	81.67	120.13	97.44	106.25	76.43
Total Specified Expenses[a]	**826.44**	**669.49**	**631.33**	**542.39**	**743.57**
Returns to Specified Expenses	**258.86**	**600.40**	**359.34**	**330.67**	**322.86**
Operating Expenses/Yield Unit	4.05	2.56	3.14	2.87	3.65
Total Expenses/Yield Unit	4.49	3.11	3.71	3.57	4.06

Continued

Table 7. Continued.

Receipts	Lonoke	Mississippi	Monroe	Woodruff	Average
Yield (bu.)	201	210	188	180	187
Price Received	5.91	5.94	5.80	5.77	5.85
Total Crop Revenue	**1188.83**	**1246.46**	**1090.75**	**1039.11**	**1094.50**
Operating Expenses					
Seed	146.16	209.96	149.28	29.41	127.43
Fertilizers and Nutrients	77.50	116.89	112.80	89.97	110.95
Chemicals	87.53	61.86	131.21	84.96	95.66
Custom Applications	36.80	56.00	69.60	51.21	47.20
Diesel Fuel	16.66	20.68	22.67	18.59	16.70
Repairs and Maintenance	19.31	22.94	22.44	22.70	20.90
Irrigation Energy Costs	15.20	39.52	39.52	54.93	37.14
Labor, Field Activities	6.98	9.14	9.98	9.57	7.74
Other Inputs and Fees, Pre-harvest	22.16	20.11	26.33	20.93	18.20
Post-harvest Expenses	121.30	126.74	113.46	108.63	112.85
Total Operating Expenses	**549.60**	**683.84**	**697.29**	**490.88**	**594.77**
Returns to Operating Expenses	**639.23**	**562.61**	**393.46**	**548.23**	**499.73**
Capital Recovery and Fixed Costs	95.77	113.98	115.51	108.22	101.71
Total Specified Expenses[a]	**645.37**	**797.82**	**812.80**	**599.11**	**696.48**
Returns to Specified Expenses	**543.46**	**448.63**	**277.95**	**440.00**	**398.02**
Operating Expenses/Yield Unit	2.73	3.26	3.71	2.73	3.19
Total Expenses/Yield Unit	3.21	3.80	4.32	3.33	3.73

[a] Does not include land costs, management, or other expenses and fees not associated with production.

Table 8. Selected variable input costs per acre for fields enrolled in the 2020 Rice Research Verification Program.

County	Rice Type	Seed	Fertilizers and Nutrients	Herbicides	Insecticides	Fungicides and Other Inputs	Diesel Fuel	Irrigation Energy Costs
Drew	RT 7521 FP	163.53	141.09	173.37	---	---	13.36	34.25
Jackson	RT 753	155.50	101.47	58.25	---	---	15.18	40.18
Lawrence	CLL 15	109.65	106.87	79.29	---	4.50	13.65	36.88
Lee	Diamond	43.35	105.90	61.21	---	---	17.47	39.52
Lincoln/Jefferson	RT 7301	140.07	146.04	114.24	---	4.50	12.03	34.25
Lonoke	RT 7301	146.16	77.50	87.53	---	---	16.66	15.20
Mississippi	RT 7321 FP	209.96	116.89	52.46	---	9.41	20.68	39.52
Monroe	XP 753	149.28	112.80	124.42	2.30	4.50	22.67	39.52
Average	**---**	**127.43**	**110.95**	**92.19**	**2.30**	**5.78**	**16.70**	**37.14**

Inheritance and Allelic Relationship of Restorability in Arkansas Restorer Lines

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Abstract

Rice (*Oryza sativa* L.) production has increased considerably after the introduction of hybrid rice technology. The process of hybrid breeding relies on developing hybrid parental lines that include male sterile lines as the female parent and fertility restorer lines as the male parent. A restorer line that carries fertility restoring (*Rf*) genes in its nucleus is an essential part of hybrid rice breeding. The University of Arkansas (UA) hybrid rice program has developed two restorer lines 367R and 396R. However, there is no information about the genetics of fertility restorability in these two lines. The objectives of this study were to demonstrate the inheritance and allelic relationships of potential *Rf* in these two lines. Three bi-parental populations were developed: one resulting from a cross between 367R and a UA advanced line RU1501139 and two reciprocal crosses between 396R and a UA advanced line RU1501047. Leave samples of F_2 plants from the population of 367R × RU1501139 and 396R × RU1501047 were collected and used for genotypic analysis. The $F_{2:3}$ lines from each population were test-crossed with a UA developed cytoplasmic male sterile (CMS) line 873A to determine their fertility restorability. The results showed that 367R and 396R each contain two fertility restoring genes in their genomes. Genotypic analysis on the population of 367R × RU1501139 detected two major QTLs on the chromosome (chr.) 10 that were co-localized with previously reported QTLs of the *Rf4* and *Rf5* genes. The results of this study can be used for developing markers for the marker-assisted selection of improved new restorer lines.

Introduction

Rice is a self-pollinated plant, which makes hybrid rice production difficult; therefore, developing a male sterile line designated as a female parent is essential for hybrid rice seed production. Male sterile florets not only have a functional stigma but also have sterile pollen that prevents self-pollination (Virmani et al., 2003). However, cytoplasmic male sterility can be restored by one or more dominant restorer genes (*Rf*) from a male restorer line (Li et al., 2009).

A restorer line is required as a male parent in hybrid rice seed production. In hybrid rice production, the female parent is a cytoplasmic male sterility (CMS) line; thus, in order to produce seeds, the CMS line should be crossed with a restorer male parent. Restorer lines carry at least one *Rf* gene with a normal or sterile cytoplasm (Virmani et al., 2003).

Yan et al. (2010) developed 13 restorer lines for the production of hybrid rice at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), Stuttgart. Among these lines, 367R and 396R showed the highest yield potential for hybrid rice cultivation. However, their *Rf* genes and the positions of these genes on the chromosomes were unknown. Therefore, the objectives of this study were to identify the inheritance (number of *Rf* genes in the genomes) and the allelic relationship between these *Rf* genes (identification of the position of *Rf* genes in the genome) of these restorer lines.

Procedures

Plant Materials

The experiments were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) in Stuttgart, Arkansas from 2016 to 2019. Six rice genotypes were used for this study, including two restorer lines 367R and 396R, male-sterile line 873A, and two advanced long-grain lines RU1501139 and RU1501047 developed by the RREC long-grain rice breeding program. The 873A is a non-aromatic long grain wild abortive type (WA) CMS line.

Phenotypic Studies

Developing Bi-parental Populations. In summer 2016, three bi-parental populations were developed, which resulted from crosses of 367R × RU1501139 and 396R × RU1501047, respectively. In 2017, the F_1 plants were grown in a greenhouse and genotyped with molecular markers to make sure the resulting plants were true hybrids. The F_2 seeds were collected from each single F_1 plant. The F_2 seeds were planted in 1-gallon plastic pots filled with Baccto® premium potting soil in a greenhouse during fall 2017. Twelve pots were placed in a plastic tub immersed in 2–4 in. of water. Fertilizer, Osmocote® (15N-9P-12K), was applied to the top of pots by adding 1/2 scoopful per pot, and pesticides were applied according to the standard recommendations in Arkansas. The greenhouse lighting system was set to 12 hours of daylight, which was ideal for rice growth. The $F_{2:3}$ seeds from each F_2 plant were harvested for the field study.

The $F_{2:3}$ lines were planted in the field. Thirty seeds from each line were planted in a row of 5-ft long spaced 16 in. apart on three planting dates: 22 May, 30 May, 6 June of 2018. Germination started on 5, 12, and 19 June, respectively. After each planting, the bays were flushed to achieve germination. Urea was applied as a source of nitrogen at a rate of 135lb N/ac before flooding the bays on 5 and 12 July at the V5 stage. The bays were flooded on

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the same day of fertilization. Weeds were controlled by pulling them manually from the field, no diseases were observed, and no chemicals were used for disease control. Meanwhile, the UA CMS line 873A was planted for test crossing in six planting dates of 10, 22, and 29 May and 12, 18, and 27 June 2018 into 1-gal plastic pots containing potting soil under greenhouse conditions. The greenhouse was programmed for 86 °F during the day and 73 °F at night with 75% humidity. Seed germination occurred 5-6 days after planting.

Test Cross Procedure

At the heading stage, five panicles from five randomly selected plants from each row were carefully collected and used for test crossing with the 873A CMS line in the greenhouse. The F_1 (test cross) seeds were harvested, and 10 seeds for each F_1 plant were planted into 1-gal plastic pots (3 seeds/pot) in a greenhouse. At panicle exertion (R3–R4 growth stages), when 1 or more florets reached anthesis, 15–20 spikelets were collected between 7:00–10:00 AM for pollen staining from 5 randomly selected plants. A total of 25 testcrosses were checked by pollen staining from each line. The pollen staining procedure is described in Table 1. In 1997, Virmani et al. classified pollen viability based on appearance and a pollen sterility/fertility ratio. Sterile pollen can appear to be translucent either in an unstained, withered, or spherical shape, while fertile pollen is stained and round (completely dark) (Fig. 1). Since the purpose of this study was to identify R lines for the hybrid rice breeding program, the pollen variability from the samples was classified into two classes of sterile (>91% sterility) and fertile (<91% sterility) (Table 2), which were determined by Virmani et al., 1997.

DNA Extraction and Genotyping

The tissue samples from each F_2 plant from the populations of 367R × RU1501139 were collected at the V5 growth stage, labeled, and freeze-dried for genotyping via Single Nucleotide Polymorphism (SNP) markers. The samples were sent to an Illumina sequencing company located in River Falls, Wisconsin, to be genotyped using 7000 SNP Infinium Rice Chip. After genotyping, the $F_{2:3}$ seeds from each single plant were harvested.

Statistical Analyses

Determination of how many restorer gene(s) were in the restorer lines 367R and 396R was conducted by using a Chi-square test. Chi-square tests were used to determine the goodness-of-fit of the observed data to the expected ratio by using Excel®. The observed data resulted from a total of five test crosses made between 873A and the $F_{2:3}$ lines previously developed. Five F_1 test crosses from each test cross were grown in the greenhouse ($5 \times 5 = 25$ F_1 test cross). The results from the test crosses were classified in all sterile plants (all S), all fertile (all F), and segregating (both F and S were observed). The Chi-square was calculated via the formula below:

$$\chi 2 = \sum \frac{(Observed\ frequency - Expected\ frequency)^2}{Expected\ frequency}$$

For example, the phenotypic ratio of fertility restoring of 3R:1S was expected for one restorer gene, and 15R:1S was expected for two restorer genes in the restorer line. JMP Pro was used to observe the association between detected quantitative trait loci (QTL) and *Rf* genes.

QTL Mapping

The linkage map was constructed with inclusive composite interval mapping (ICI) software with the genotypic and phenotypic data collected from the F_2 and $F_{2:3}$ populations to identify QTL associated with the restorability (Meng et al., 2015). The Kosambi function was used for the linkage map, and the markers were ordered into the linkage map based on SNP markers. For identification of any QTL and its power, an Inclusive Composite Interval Mapping was performed using the additive and dominant QTL function with a 2.5 LOD for threshold. Only QTL with a *P*-value ≤ 10^{-3} (LOD score of ≥ 3.0) was declared as a major QTL. The detected QTL associated with fertility were compared to the previously reported QTLs regions using the Gramene database (https://www.gramene.org/).

Results and Discussion

Inheritance Analysis

As shown in Table 1, the majority of $F_{2:3}$ lines from both populations of 367R × RU1501139 and 396R × RU1501047 were segregating for fertility. The Chi-square test for 367R population ($x^2 = 0.7504$, *P*-value = 0.3863) and 396R ($x^2 = 0.3604$, *P*-value = 0.5483) fit into the 15F:1S ratio (Fig. 2). Therefore, 367R and 396R each possesses two dominant *Rf* genes in its genome.

QTL Analysis for Allelic Relationship

To detect the position of the *Rf* genes in the 367R and 396R genomes, the populations derived from 367R and 396R were genotyped using 7K SNP genotypic markers. Among 300 F_2 plants from populations derived from 396R, only 723 polymorphic SNP markers were identified; thus the detection of major QTLs in this population was not possible because of low LOD values. However, among 295 F_2 plants from 367R x RU1501139 population, 2595 polymorphic markers were identified. The QTL analysis on the population using QTL ICI Mapping software detected one region with a LOD > 3.0 on chr. 10. Two adjacent QTLs associated with fertility were detected on chr. 10. The first QTL was positioned between 1.45×10^7 and 1.46×10^7 bp, which was co-localized with the previously reported restorer gene *Rf5*. Several SNP markers, such as SNP-10557866 and SNP-10562661, with 17–18 % phenotypic variations explained (PVE) were located in the same regions. The second QTL was located between 1.93×10^7 and 1.98×10^7 bp that was co-localized with the previously reported gene *Rf4*. Several markers with significant *P*-value (*P*-value < 0.01), including SNP-10.18986400, SNP-10.18995837, SNP-10735601 and SNP-10.20184542, were located in the same region with around 2–3% PVE values (Table 3).

The results showed that there is a strong association between *Rf5*, detected QTL, and two SNP markers (SNP10557866 located in 14,503,250 bp and SNP10562661 located in 14,664,0458 bp) positioned on the left and right side of the gene. There was a minor linkage association between detected QTL and *Rf4*, and the SNP marker to this gene was SNP-10.19278971 (located in 19,350,417 bp) and 10734306 (located in 19,860,755 bp) positioned on the right side of the gene (Fig. 3).One of the two common restorer genes *Rf4* was located on chr. 10 (Gramene database, 2020). The *Rf4* gene was identified as a restorer gene on the long arm of chr. 10 (Zhang et al., 1997). Although *Rf4* is a major fertility gene, there is a low linkage associated with the detected QTL. Pranathi et al. (2016) reported that when the two major genes of *Rf3* and *Rf4* present in a genome, one displays as a major, while the other exhibits as a minor gene. Therefore, it can be assumed that in 367R, *Rf5* has a major gene influence, while *Rf4* is minor.

We inferred the origin of the gene of interest by analyzing the history of the crosses that led to the creation of the 367R and 396R restorer lines. The 367R was derived from the cross Katy/IR30//IR140 (PI 458443)/Jasmine 85 (PI 595927). A previous study showed that IR262, one of the parents of cultivar Jasmine 85, possesses *Rf4* in its genome (Bharaj et al., 1995). Therefore, it can be assumed that *Rf4* is originated from Jasmine 85. Moreover, it has been reported that Tetep and IR262, parents of Katy and Jasmine 85, respectively, possess *Rf5* in their genomes (Bharaj et al., 1995). Therefore, it can be assumed that the *Rf5* gene was originated from Katy or Jasmine-85. Likewise, the *Rf* genes in 396Rare likely derived from its parental line IR1586-2 according to Zongbu Yan (pers. comm.), who developed the line from the cross Francis/4/IR1586-2(PI 400793)/3/Bengal//L202/Lemont.

Practical Applications

Two major QTL were identified in chromosome 10, one, QTL10-1, is located between SNP-10.18986400, SNP-10.18995837 and 10735601. A previous study reported that the restorer gene *Rf4* is located in this QTL. The second QTL, QTL10-2, is positioned between SNP markers of 10557866 and 10562661. Previous reports showed that a restorer gene *Rf5* is situated in this QTL. These markers can be used in marker-assisted selection in the breeding for adapted restorer lines for hybrid rice.

Acknowledgments

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Table 1. Pollen-stain protocol (Guzman et al., 2011).

Step	Process
1	Stock solution prepared with 100 mL distilled water, 1 g iodine crystals, and 3 g potassium iodide.
2	Dilute the stock solution at a rate of one-unit of stock solution to four-units of distilled water.
3	Collect several young spiclets at the flowering phase.
4	Anthers are removed manually by separating palea and lemma.
5	Place the anthers onto a proper slide and treat with I2K solution for 5 minutes.
6	Check the anthers with a microscope using a 10x or 20x lens.
7	Fertile pollens have a dark-black color; sterile pollens will have translucent color (Fig. 1).
8	Visually estimate the pollens to determine the sterility level.

Table 2. Chi-square test from the phenotypic ratio of test cross with $F_{2:3}$ line.

Restorer Line	Phenotypic Ratio[a]	*P*	*P*-value	*P* < 0.01	*P* < 0.05
367R	15R:1S	0.7504	0.3863	0.5636	0.5483
396R	15R:1S	0.3604	0.5483	0.7640	0.5636

[a] The phenotypic ratio is calculated based on lines with restorer gene(s) including all R and segregating to all sterile line. The 15:1 ratio indicating presence of two *Rf* genes in the genome.

Table 3. List of parental detected quantitative trait loci (QTL).

QTL	Parental origin of positive allele	Chromosome	LeftMarker	RightMarker	Base Pair Position	Logarithm of the odds
qTL-1	367R	10	SNP-10557866	SNP-10760864	14503250	3.5476
qTL-2	367R	10	SNP-10735601	SNP-10.20184542	20743450	0.6819

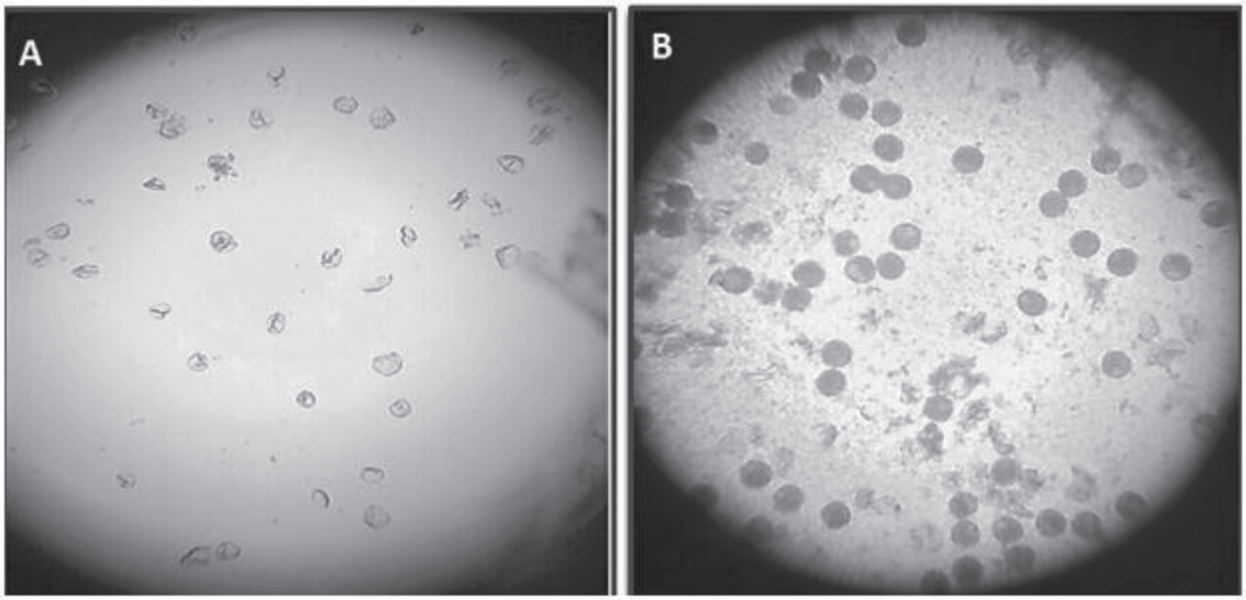

Fig. 1. Pollen grain appearance under a microscope (10x) after staining (A) sterile pollen, (B) fertile pollen.

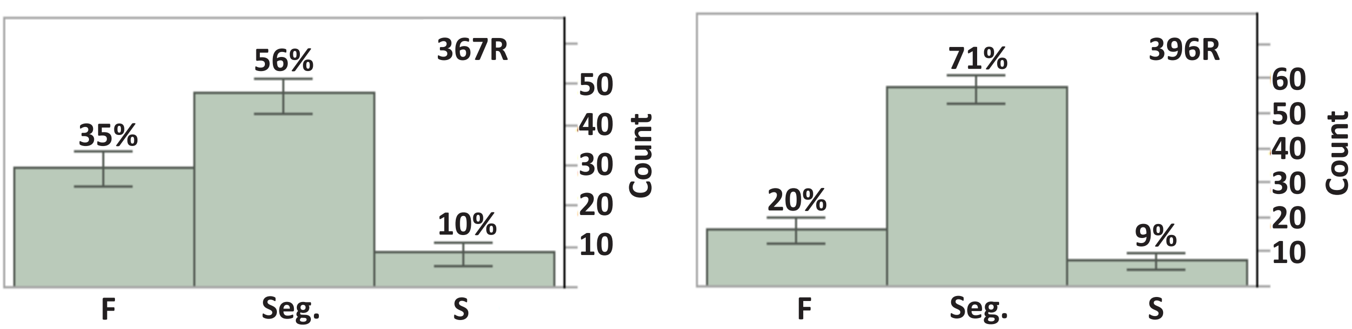

Fig. 2. Fertility frequence of 367R and 396R. Classification of $F_{2:3}$ lines; F = all fertile; Seg. = partial fertile; S = all sterile.

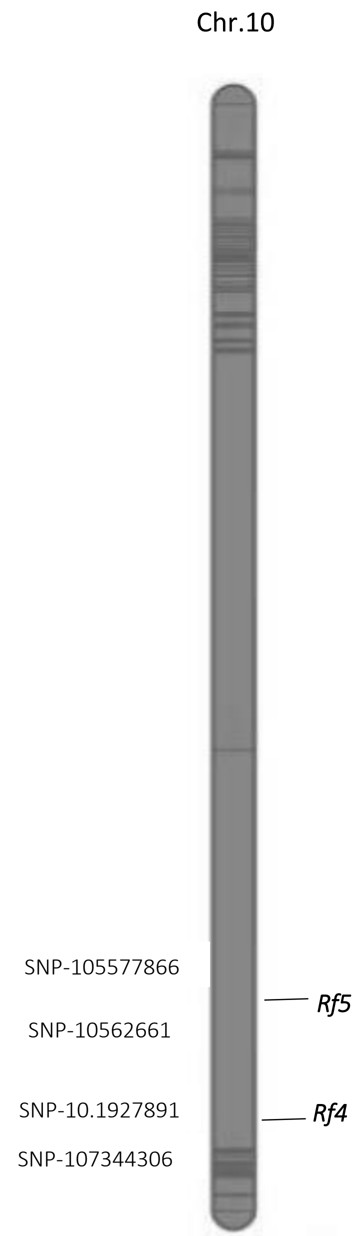

Fig. 3. Linkage map and quantitative trait loci position for restorer gene.

Molecular Analysis of the Rice Blast Resistance Gene *Ptr* Increases Accuracy of Disease Resistance Predictions at the *Pi-ta* Locus

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Abstract

In 2020 the molecular genetics lab added a new marker linked to the rice blast resistance gene *Ptr* to its toolbox of trait-linked markers, which was used to screen a set of 88 early-generation test samples from the medium-grain breeding program. The results showed that the marker identified 33 samples that had the susceptible allele of the *Ptr* gene, including 13 samples that amplified the resistant allele of the *Pi-ta* gene. Molecular genetics staff also performed genetic analysis on 8 major projects for rice breeding involving DNA marker-assisted selection (MAS) for the important traits of cooking quality, aroma, rice blast disease resistance, plant height, leaf texture, and the herbicide resistance technologies Clearfield and Provisia at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC). The Molecular Genetics lab screened 4,185 test samples with up to 21 markers. The rice molecular analysis projects included parental materials, male sterile and restorer lines, selected F_1 hybrid lines, and early and advanced generations of conventional breeding materials currently in development. In total, the lab generated 23,103 data points for 6 clients. The work was accomplished using 64 DNA template plates, 258 PCR plates, 55 runs on the ABI 3500xL to analyze simple sequence repeat (SSR) markers, and 134 KASP runs to analyze single nucleotide polymorphism (SNP) markers.

Introduction

Over the last 20 years, much of the effort of molecular genetics has been devoted to the genotypic characterization of parental lines and progeny in the development of new long-grain and medium-grain cultivars. One of the major goals of rice breeding is to increase yields, which can be improved by incorporating genetic resistance to rice blast disease. The majority of this effort has focused on the rice blast resistance gene *Pi-ta*. Jia et al. (2004) describes *Pi-ta* as an important gene that confers resistance to the major races of the rice blast fungus predominant in Arkansas. Three different types of molecular markers associated with the *Pi-ta* gene have been deployed in DNA marker-assisted selection (MAS) for the goal of accurate phenotype prediction of early generation breeding materials. However, in actual field and greenhouse blast studies, the plants did not always exhibit the level of resistance that the *Pi-ta* marker results had predicted (Gibbons, pers. comm.). A search was initiated to find a marker system that would predict the resistance phenotype at the *Pi-ta* locus accurately and consistently.

Plant pathologists were aware of 2 other genes associated with *Pi-ta*, *Pi-ta2,* and *Ptr*, but it was not until 2018 that the *Ptr* gene was cloned and characterized, and a DNA marker tightly linked to the *Ptr* gene was developed (Zhao et al., 2018). It was reported that *Ptr* function was independent of *Pi-ta* and that there was a distinct difference in the resistance spectrum of plants with resistant alleles of both the *Pi-ta* and the *Ptr* genes and plants carrying only the *Pi-ta* resistant allele (Zhao et al., 2018). In this study, plants carrying resistant alleles at both genes were resistant to a much broader range of blast isolates (Zhao et al., 2018). Further studies differentiated the rice blast races to which the 2 haplotypes conferred resistance. Plants with only the *Pi-ta* resistant allele exhibit resistance to 2 races of the rice blast pathogen—IB49 and IC17, whereas plants carrying the *Ptr* resistant allele display resistance to 9 rice blast races—IA45, IB1, IB49, IB54, IB45, IH1, IG1, IC17, and IE1 (Jia et al., 2019). Using the *Ptr*-linked Z12 marker to assess the allele status of the *Ptr* gene gives us the ability to more accurately predict disease resistance at the *Pi-ta* locus, making DNA MAS more successful.

The objective of this ongoing study is to apply specific DNA marker technology to assist with the development of elite cultivars adapted to Arkansas with improved cooking quality and rice blast disease resistance. The goals include (i) characterizing parental materials on a molecular level for important agronomic traits and purity, (ii) performing DNA MAS of progeny to confirm identity and track gene introgression, and (iii) ensuring seed quality and uniformity by eliminating off types.

Procedures

Some samples consisted of leaf tissue from individually tagged greenhouse plants that were collected in manila coin envelopes and kept in plastic bags on ice until placed in storage at the molecular genetics lab. Other samples were brought to the molecular genetics lab as seeds, which were germinated at 84.2 °F (29 °C) in Petri dishes in an incubator (VWR Scientific, Radnor, Pennsylvania). The leaf tissue was stored at -112 °F (-80 °C) until sampled. Total genomic DNA was extracted from the leaf tissue using a rapid method with Sodium hydroxide/Tween 20 buffer,

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10-min incubation at 203 °F (95 °C), and neutralization with 100 mM TRIS-HCl, 2 mM EDTA (Xin et al., 2003).

Each set of DNA samples was arrayed in a 96-well format, processed through a OneStep-96 PCR Inhibitor Removal system (Zymo Research Corporation, Irvine, California), and used directly as the starting template for simple sequence repeat (SSR) and insertion-deletion (InDel) marker analysis. For Kompetitve Allele Specific PCR (KASP) or PCR Allele Competitive Extension (PACE) reactions, the DNA plate was diluted 1:5 in water to prepare the reaction template.

Polymerase Chain Reaction of SSR and InDel markers was conducted using primers pre-labeled with attached fluorophores of either HEX, FAM, or NED by adding 2 µl of starting DNA template in a final reaction volume of 25 µl and cycling in a Mastercycler X50s thermal cycler (Eppendorf North America, Inc., Westbury, New York) for 35 cycles of a traditional 3-step PCR protocol. To save on processing and analysis costs, PCR plates were grouped according to allele sizes and dye colors and diluted together. The PCR products were resolved using capillary electrophoresis on an ABI 3500xL Genetic Analyzer (Applied Biosystems, Foster City, California). Data were analyzed using GeneMapper Software V5.0 (Applied Biosystems, Foster City, California).

The KASP reactions were prepared by adding 5 µl of each DNA sample and 5 µl of the 2X Master Mix containing 0.14 µl of Assay Mix to the wells of a 96-well opaque qPCR plate (LGC Biosearch Technologies, Teddington, Middlesex, U.K.). The plate was then sealed with qPCR film (LGC Biosearch Technologies, Teddington, Middlesex, U.K.), and the KASP reactions were cycled in a Mastercycler X50s thermal cycler (Eppendorf North America, Inc., Westbury, New York) using a 2-step 135 °F (57 °C) thermal cycling protocol. The plates were then allowed to cool to room temperature prior to reading on a BMG Labtech FLUOstar Omega SNP plate reader (LGC Biosearch Technologies, Teddington, Middlesex, U.K.). Detected fluorescence was analyzed using KlusterCaller software (LGC Biosearch Technologies, Teddington, Middlesex, U.K.).

Other markers were used to analyze the test samples in addition to the *Pi-ta* marker Pi-indica and the *Ptr* gene marker Z12. They include *Pi-k* rice blast resistance gene marker RM224, and the markers to assess cooking quality included RM190, *Waxy* Exon 1, *Waxy* Exon 6, and *Alk* (Data not shown). The markers Pi-indica, Z12, RM224, and RM190 were grouped together in the same ABI plate, while the remaining cooking quality markers were analyzed using the KASP system.

Results and Discussion

Of the 88 samples, 57 had *Pi-ta*, 8 were segregating for the gene, while 23 were susceptible to disease at that locus. Fifty of the samples had *Ptr*, 5 were segregating for the gene, and 33 amplified the susceptible allele. Of the homozygous resistant samples, 13 had only *Pi-ta* and were susceptible at *Ptr*, 6 samples had only *Ptr* and were susceptible at *Pi-ta*, and 44 plants had the resistant genotype at both *Pi-ta* and *Ptr*. Seventeen of the samples were susceptible at both *Pi-ta* and *Ptr*. See Table 1.

These results show that with the addition of the Z12 marker to assess the *Ptr* gene independently of *Pi-ta*, it is now possible to distinguish between haplotypes conferring resistance to only 2 rice blast races and those conferring resistance to 9 races. Without Z12 marker data, all 57 of the plants homozygous for *Pi-ta* would have been selected for advancement, including the 13 plants lacking *Ptr* and therefore resistant to only 2 races of rice blast disease. However, the 6 plants homozygous for *Ptr* but lacking *Pi-ta* would have been discarded despite being resistant to 9 races. The added information from Z12 marker analysis allows for more accurate predictions of the disease resistance phenotype.

Practical Applications

Marker-assisted selection enables rice breeders to make their selections rapidly and efficiently, saving time, field resources, and labor. Many traits would require the plant to grow to maturity to assess them phenotypically; and with multiple rice blast resistance genes, determining the ones conferring resistance would be difficult through a race differential study. Compilation of all the marker analyses conducted enables the rice breeder to make selections of plants with desirable agronomic traits. Using markers allowed selection to take place in an early generation so that most of the investment in development could be focused on promising lines and not wasted on materials destined to be discarded.

Acknowledgments

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Table 1. Haplotypes of Blast Disease Resistance Genes *Pi-ta* and *Ptr* in 88 Test Samples.

Genotype	Resistant	Segregating	Susceptible
Pi-ta	57	8	23
Ptr	50	5	33
Pi-ta Only	13	3	
Ptr Only	6	0	
Pi-ta + *Ptr*	44	5	

Breeding and Evaluation for Improved Rice Varieties: The Arkansas Long Grain Rice Breeding and Development Program

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Abstract

The Arkansas Long Grain Rice Breeding Program is continuously developing new long- and medium-grain cultivars as well as specialty cultivars, including aromatics. Strict evaluations and selections are conducted based on the desirable characteristics. Characteristics that are important include high yield potential, excellent milling yields, good plant stature, pest and disease resistance, and superior grain quality (i.e., low percent chalk, cooking, processing, and eating). The Stuttgart initial test and advance tests, including multi-location statewide Arkansas Rice Performance Trial (ARPT), are conducted annually to identify best lines for potential release. This report describes potential new lines entering the advanced stage of the breeding program and the breeding efforts conducted at the University of Arkansas System Division of Agriculture.

Introduction

The Arkansas rice breeding program develops new varieties through the incorporation of resistance and/or tolerance to the major rice diseases (specifically rice blast, sheath blight, and bacterial panicle blight) and evaluates lines with excellent grain and milling yields and grain quality. This is achieved through crossing, backcrossing, gene mapping and identification, and other feasible techniques like marker-aided selection. New herbicide-tolerant traits are also being incorporated into the germplasm pool, such as Provisia. Each year, more than 600 new entries of conventional and Clearfield long-grain breeding lines are being tested in the Stuttgart initial trial (SIT), preliminary trial (PRELIM), and advance tests such as the Arkansas Rice Performance Trial (ARPT). Cooperating with the state Rice Extension Specialist to conduct a comprehensive rice variety testing program in all major rice-producing areas of the state is valuable in evaluating the best lines across different geographical locations and necessary for decision-making in future varietal releases.

Procedures

The breeding program utilizes different plant breeding methodologies and breeding support programs to develop new varieties as well as improve the populations and the germplasm pool. Developing new varieties starts by selecting and crossing the best parental lines and generating a large segregating population with different trait combinations. Visual selection is an important aspect in early generations. The best material is advanced by visually choosing plants that have desired characteristics such as short stature, better straw strength, erect leaves, longer panicles, and diseases free leaves.

Improving grain yield is one of the major objectives of the breeding program; thus, hundreds of crosses are made to get the best combination of traits. Milling yield and quality are also essential traits that the program identifies relatively early in the breeding process. Starting from panicle rows at the F_4–F_5 stage, 60 g of samples are milled to determine total and head rice yield. Preliminary, Stuttgart initial test (SIT) and Advance test (ARPT) uses 100 g of samples in three replicates. Testing for grain quality parameters including amylose, gelatinization temperature, grain dimensions, and chalk are done in Riceland Foods laboratory. The program continuously uses the Puerto Rico winter nursery to accelerate the breeding process by advancing the lines as well as increasing breeder seed. All entries entering yield trials are evaluated for disease through greenhouse screening and natural infection under field conditions. Plants were inoculated in the greenhouse with blast (IE-1K, IC-17, IB-49, IB-17, IB-1), in the field for sheath blight, and were carefully scored by the pathology group. Natural disease infections under field conditions were also assessed as well as general physiological disorder observations such as straighthead. The program routinely uses DNA markers to distinguish lines with genes resistance to blast and grain quality, such as amylose, gelatinization temperatures, and other important traits. Recently, genetic markers were used to identify panicle rows with the resistance gene *Pi-40* that confers durable resistance to rice blast. This is an ongoing program

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that will add a new resistance gene to our germplasm pool. The statewide testing program (ARPT) is conducted every year by the extension agronomist Jarrod Hardke which includes current varieties and promising lines developed from the Arkansas rice breeding program.

Results and Discussion

In 2020, there were a total of 634 long-grain entries in the yield trials conducted in the Rice Research and Extension Center. The entries came from the following: 86 entries from the Clearfield Arkansas Performance Tests (IMIARPT and IMIARPTKM), 187 from the Clearfield Stuttgart initial test (IMISIT), 132 entries from the conventional Stuttgart initial test (SIT), 33 entries from the aromatic advance test (AROAYT), 44 entries from the aromatic Stuttgart initial test (AROSIT), and 149 entries from the preliminary test (Prelim).

About 2,000 F_2 plants derived from four populations of Provisia × elite lines were screened with the Provisia marker in 2020. A total of 801 plants that were homozygous for the Provisia trait were selected by field screening and using marker-assisted selection. Two panicle rows of each homozygous line are planted in the Winter Nursery in Puerto Rico. Additionally, 2,000 panicle rows are planted in Puerto Rico from the various Long-grain (L-pan) and Puerto Rico (P-pan) panicle rows originally planted in Stuttgart. These lines are in F_5 to F_6 generation and are expected to enter a large Stuttgart initial trial in 2021.

Statewide performance tests (ARPT) in Table 1 conducted in Clay Co. (CC), Northeast Research and Extension Center (NEREC), Desha Co. (Desha), Pine Tree Research Station (PTRS), and Rice Research and Extension Center (RREC) showed a promising line 20AR093 having an average yield of 217 bu./ac compared to CLL16, CLL15, and Diamond with 205, 200, and 208 bu./ac, respectively. Another potential line 20AR085 has a grain yield of 207 bu./ac comparable to Diamond but with an excellent milling yield of 62/71 (%Head/%Total) shown in Table 2. Both new entries are included for further testing in 2021 ARPT and URRN, as well as in other advanced yield tests in Stuttgart.

A number of conventional breeding lines in the SIT exhibited high yield potential compared to the check variety Jewel and Diamond. Table 3 showed lines STG17L-09-142 and STG16L-14-163 produced 213 and 210 bu./ac grain yields and 57/72 and 57/71 milling yields, respectively. In comparison, the check varieties Diamond and Jewel had 201 and 188 bu./ac grain yields, and 54/70 and 57/69 milling yields, respectively. Three additional lines STG18P-04-119, STG18L-01-194, and STG17L-04-037 had a higher yield potential and better or comparable milling yield than the check varieties.

Practical Applications

The successful release of Diamond in 2016, ARoma 17 in 2018, and Jewel in early 2020 demonstrated the capability of the breeding program to continuously develop high yielding varieties with excellent milling and good grain quality for rice producers in Arkansas. Improvements through introducing value-added traits such as new blast resistance genes through plant introductions and germplasm exchange will continue to be an important means in increasing the genetic diversity, which will certainly lead to more potential lines to be selected in the future.

Acknowledgments

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Table 1. Yield, 50% days to heading, height, and stalk strength of selected Clearfield lines in 2020 Arkansas Rice Performance Trials (ARPT) conducted in Clay County (CC), Northeast Research and Extension Center (NEREC) at Keiser, Pine Tree Research Station (PTRS) near Colt, Desha County (Desha), and Rice Research and Extension Center (RREC) at Stuttgart, Arkansas.

	Yield						50%		Stalk
Cultivar	CC	NEREC	PTRS	Desha	RREC	Mean	Heading	Height	Strength[a]
	(bu./ac)						(days)	(in.)	
20AR093	261	212	197	227	186	217	82	37	1.0
20AR085	264	217	193	185	173	207	82	37	1.0
CLL16	257	203	185	205	178	205	85	38	1.2
CLL15	238	191	190	183	199	200	81	33	1.0
Diamond	270	190	183	226	169	208	83	37	1.0

[a] Relative stalk strength based on field tests using the scale: 1 = very strong straw, 5 = very weak straw; based on percent lodging.

Table 2. Milling yield of selected Clearfield lines in 2020 Arkansas Rice Performance Trials (ARPT) conducted in Clay County (CC), Northeast Research and Extension Center (NEREC) at Keiser, Pine Tree Research Station (PTRS) near Colt, Desha County (Desha), and Rice Research and Extension Center (RREC) at Stuttgart, Arkansas.

	Milling yield					
Cultivar	CC	NEREC	PTRS	Desha	RREC	Mean
	--------------------%HR/%TR[a]--------------------					
20AR093	57/70	57/68	59/69	59/69	62/70	59/69
20AR085	60/71	59/69	62/70	62/71	65/72	62/71
CLL16	53/69	56/68	61/69	60/69	63/70	59/69
CLL15	61/70	60/69	62/69	62/69	62/69	61/69
Diamond	59/71	58/70	62/71	60/70	61/70	60/70

[a] Milling figures are %head rice/% total rice.

Table 3. Yield, 50% days to heading, height, and milling yield of selected conventional experimental lines in 2020 Stuttgart Initial Test (SIT) conducted in Rice Research and Extension Center at Stuttgart, Arkansas.

Entry	Yield	50% Heading	Height	Milling yield
	bu./ac	(days)	(cm)	%HR/%TR[a]
STG17L-09-142	213	88	102	57/72
STG16L-14-163	210	90	111	57/71
STG18P-04-119	208	94	113	64/73
STG18L-01-194	207	95	109	57/71
STG17L-04-037	207	94	107	56/70
Diamond	201	85	102	54/70
Jewel	188	85	102	57/69

[a] Milling figures are %head rice/% total rice.

Screening for High Night Temperature Tolerance of Popular Arkansas Varieties and Advanced Lines

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Abstract

Nineteen long-grain advanced lines and released varieties were tested for performance under HNT conditions. Experiments were conducted evaluating the percentage of filled grain per panicle (filled grain), grain yield, head rice yield (HRY), and degree of endosperm chalk (chalk) under two treatments: Control [73.4 °F (23 °C)] and HNT [82.4 °F (28 °C)] commencing at the R2 stage (flag-leaf collar formation) until physiological maturity. RU1601010, Jewel, 11X185 (hybrid) had seed filling declines of 2, 7, and 10%, respectively, relative to the control. Diamond's grain filling declined by 32% under HNT. Similar to grain filling, HNT treatment resulted in a decrease in grain yield. The UA hybrid 11X185, RU1601010, and Jewel also showed the least grain yield declines with 13%, 22%, and 28%, respectively. The HRY declines for most varieties under HNT, ranging from 0.61% to 7.00%, with more significant effects on RU1601010, Cypress, and RU1601121. The degree of chalk increases under HNT; however, ARoma 17 and RU1601121 showed minimal increases of 1.33% and 4.94%, respectively. Overall, we can conclude that tolerance to HNT is present to some degree within Arkansas varieties and advanced lines. We are proceeding with the development of lines/varieties with both high yield and stable grain quality under HNT using a crossing scheme involving multiple parentage.

Introduction

High night temperature (HNT) affects rice plants detrimentally, with more serious effects when it occurs during the reproductive stage. Decreased rough rice grain yield, increased grain chalkiness, and reduced head rice yield (HRY) are among the parameters negatively affected by HNT (Counce et al., 2005; Mohammed and Tarpley, 2009). In our previous report, we confirmed the susceptibility of major Arkansas varieties Diamond (long-grain) and Titan (medium-grain) to a probable Arkansas HNT scenario using large walk-in growth chambers (Esguerra et al., 2020). In addition, we reported that the HNT effect varies depending on the time of occurrence during the reproductive stage. Spikelet fertility (SF) and grain yield were unaffected by HNT commencing at the R5 stage (elongation of at least one grain on the main stem panicle) but showed a variety-specific response at the R2 stage (flag-leaf collar formation). Head rice yield declined in most varieties under HNT, with more noticeable effects occurring at the R5 stage. In terms of chalkiness, most varieties have shown an increased degree of endosperm chalk (DEC) at both R2 and R5 stages under HNT. Also from this experiment, we have confirmed the tolerance of the N22 variety to HNT as manifested on its comparable grain yields under both control and HNT treatments. While the variety Kaybonnet has shown lower chalk values under HNT at the R2 stage.

To continue our HNT tolerance screening of high-yielding advanced lines and validation of our two-year field experiment results (Hemphill et al., 2020), we conducted two batches of experiments for 2020. Our specific goal is to document and evaluate under the HNT condition the performance of advanced lines in the pipeline of the University of Arkansas System Division of Agriculture's Rice Breeding Programs and validate the performance of varieties that showed stable yield and grain quality from our two-year field experiments. Here we report the performances of selected advanced lines and varieties, along with susceptible and tolerant checks under HNT in comparison with a control treatment focusing on SF, grain yield, HRY, and DEC.

Procedures

Two batches of experiments were conducted to screen a total of 19 varieties and advanced lines (Tables 1 and 2). For this year, we focused on screening for HNT tolerance for long-grain varieties as medium-grain varieties appeared to be less susceptible to HNT (Esguerra et al., 2020). Our last year's results lead us to focus on HNT stress commencing at the R2 stage, as this affects both the yield and grain quality of the rice plants. The 19 genotypes screened included 8 advanced lines (19AYT57, 19AYT56, RU1601010, RU1801101, RU1801145, RU1801169, RU1601121, RU1701185), one experimental hybrid (11X185), and 10 released varieties (CLL16, CLL15, Diamond, LaGrue, Jewel, ARoma 17, CL153, Cypress, Rondo, and Roy J). Also included on every batch were the HNT tolerant check N22 and the susceptible check ZHE 733.

For both experiments, the following methodologies were followed: Growth chamber temperatures were precisely controlled to obtain temperatures ranging from a minimum to a maximum and back down to a minimum during each day's cycle. The variation within each range was quite small—usually less than 1 °C within the setpoint. Two night temperatures were compared using large

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growth chambers: Control [73.4 °F (23 °C)] and HNT [82.4 °F (28 °C)], that lasted from 20:00 to 6:00. Day time chamber settings (minimum to maximum in progression from dawn to early afternoon and maximum to minimum from early afternoon to dark) for both chambers were: temperature from 86.0–91.4 °F (30–33 °C), relative humidity (RH) 70–75%, irradiance 390 to 1200 µmoles/m^2 s, and CO_2 at 550 ppm. Seedlings were raised in the greenhouse and grown in 4 × 4 × 10 in. (length by width by depth) rectangular pots containing a 3:2:1 ratio of silt loam topsoil, potting mix (SunGro MM360), and sand. Two seeds per variety were sown in each pot and thinned to 1 seedling 2 weeks after sowing (WAS). Fertilization was administered per pot with the following volume, type, and schedule: 50 mL of Peter's solution (20-20-20) (460 g diluted in 25 gal water) at 3 WAS; 50 mL of Urea (46-0-0) (3 mg N/mL) at 5 WAS; and 50 mL of Urea (46-0-0) (1 mg N/mL) at the R2 stage. Fifteen pots per variety served as the experimental unit, which were placed together with another 15 pots of a different variety in a rectangular tub (36 × 24 × 8 in.). The reduction in the experimental unit size allowed us to screen more varieties this year. The RH inside the greenhouse was 60–70%, while day and night temperatures were 86.0–89.6 °F (30–32 °C) and 73.4–78.8 °F (23–26 °C), respectively. Natural sunlight served as the major light source in the greenhouse supplemented with metal halide lighting to provide additional light and a 13-hour day length. When moved inside the growth chambers, the experiments were arranged in a completely randomized block design with 3 blocks.

From each plot, the SF, which is the percentage of filled grains relative to the total number of grains, was determined from 10 randomly sampled main stem panicles. Grain yield refers to the threshed grain weight per tub dried to a moisture content of 12.5% using a chamber set at 50% RH and 75.2 °F (24 °C) temperature. For HRY, 35-g rough rice were de-hulled twice using a Mini-testing Husker (Satake, Hiroshima, Japan), milled using Zacarria PAZ-1/DTA Lab Rice Mill (CRZ, Anna, Texas) for 1 min, and divided into whole and broken grains using a Zaccaria cylinder grader (CRZ, Anna, Texas; cylinder groove: 5.5 mm for long-grain and 4.5 mm for medium-grain). The proportion of whole-grain weight over the original rough rice sample weight adjusted to the standard milling surface lipid content (SLC) of 0.50, referred to the HRY. The SLC was determined by scanning 20 g of head rice using near-infrared reflectance (NIR, DA7200, Perten Instruments, Hägersten, Sweden). For DEC, two subsamples of 10 g head rice were scanned using a SeedCount Image Analyser (SeedCount SC5000TR, Next instrument Pty Ltd., Condell Park, NSW, Australia) where DEC referred to the percentage chalk area of the scanned head rice. Data were analyzed using SAS v. 9.4 (SAS Institute, Inc., Cary N.C.).

Results and Discussion

The SF data presented in Table 1 shows that thirteen of the screened varieties have poor seed setting of less than 50% even under control conditions. This suggests a problem with either the plants or the conditions. The relative humidity in the growth chambers was only controlled at the lower limit of relative humidity and not at the upper limit. In the succeeding experiments, we are exploring ways to control the humidity in the upper range. Considering only those varieties/lines that showed more than 50% SF in the control, RU1601010 and Jewel appeared to be HNT tolerant as their SF declined only about 2.38% and 6.96 %, respectively, relative to the control treatment. Interestingly, the SF decline under HNT treatment for both RU1601010 and Jewel were even lower than that of N22 (tolerant HNT check), which showed an 8.75% decline. The experimental hybrid 11X185 also appeared to show some HNT tolerance, having a 10% SF decline under HNT treatment. Among the materials screened, Diamond appears to be the most susceptible, having an SF decline of about 32%. This further confirms the observations we had from our 2019 growth chamber experiments (Esguerra et al., 2020). Other varieties that showed a minimum of 50% SF in the control and have lower than 20% decline in SF under HNT treatment include ARoma 17, LaGrue, and RU1601121. Grain yield results (Table 1) were similar to the SF observations, which are again consistent with our previous results, making SF a good indicator of grain yield under HNT treatment. However, it should be noted that across all the materials tested, the percentage decline in grain yield is always greater than the percentage decline in SF. Jewel, RU1601010, 11X185, ARoma 17, LaGrue, and RU1601121 were the best performing materials under HNT treatment. Due to the limited amount of grain, particularly under HNT treatment, and the required amount for milling, we were not able to obtain HRY and chalk readings on some lines/varieties. Except for 19AYT56, all varieties showed a decline in HRY under HNT ranging from 0.61% to 7.00% (Table 2). Despite this decline, only RU1601010, Cypress, and RU1601121 showed a significant decline in HRY under HNT. This is again consistent with our previous results that HNT effect at R2 stage is less detrimental compared with when it occurred during the later reproductive stage, particularly R5 (Esguerra et al., 2020).

In general, all the materials tested showed an increase in DEC under HNT, suggesting that selection for HNT tolerance in terms of chalk values should be towards those materials that had the least increase in chalk incidence. Notably, among those that appeared to show HNT tolerance in terms of SF and Yield, ARoma 17 had the least increase in DEC of only about 1.33% while RU1601121 ranked second with an increase of 4.94%. Other varieties/lines that appeared to be less affected by HNT in terms of chalk (less than 5% increase in DEC) and have lower chalk values under control (less than 6% DEC) include RU1801169 and Cypress.

No advanced lines tested appeared to be resistant to HNT for yield or quality, but some were better than others. This suggests that resistance or tolerance can be incrementally improved. Overall, promising differences in responses to HNT exist among advanced lines and released varieties. To develop lines with stable grain yield and acceptable grain quality under HNT, a crossing scheme involving multiple parentage is necessary as existing varieties/advanced lines have shown variation in yield and grain quality under HNT. To exploit these differences, our group made multiple cross combinations of lines to achieve the goal of producing lines with improved and acceptable HNT tolerance (high yield and good quality). These crosses were based on our findings from the previous years, and details of the cross are presented in Table 3.

Practical Applications

Documentation of the performance of advanced lines and varieties under HNT are valuable information for RREC's rice breeding programs. This would serve as a guide on materials that need to be avoided or have to be improved to be more HNT tolerant. Crosses developed by the team can be further selected as a possible breeding line, released variety or parents for future crosses.

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Table 1. Spikelet fertility and grain yield of 21 selected advanced lines, varieties, and checks subjected to two night-temperature treatments: Control at 73.4 °F (23 °C) and high night temperature (HNT) at 82.4 °F (28 °C) at R2 stage (flag-leaf collar formation).

Batch	Spikelet Fertility		Grain yield	
Variety[†]	Control	HNT	Control	HNT
	---------------------(%)---------------------		--------------------(g)--------------------	
1				
11X185	65.08 a[‡]	55.51 a	128.98 a	112.63 a
19AYT57	34.00 a	29.28 a	50.43 a	37.59 a
19AYT56	33.67 a	37.40 a	48.17 a	41.14 a
CLL16	33.81 a	11.26 a	48.17 a	13.71 a
DIAMOND	72.84 a	40.60 a	106.56 a	48.14 a
JEWEL	68.86 a	61.90 a	96.58 a	69.62 a
N22	78.31 a	69.55 a	134.66 a	116.75 a
RU1601010	51.87 a	49.49 a	86.89 a	67.85 a
RU1801101	12.72 a	13.49 a	18.95 a	26.49 a
RU1801145	48.12 a	30.62 a	90.26 a	51.34 a
RU1801169	20.71 a	15.68 a	43.50 a	28.30 a
ZHE 733	28.36 a	14.40 a	36.24 a	13.19 b
2				
AROMA 17	56.73 a	43.58 a	85.97 a	56.40 a
CL153	33.21 a	13.34 a	45.47 a	20.53 a
CLL15	23.73 a	7.54 b	45.63 a	9.10 b
CYPRESS	35.51 a	18.45 b	55.77 a	26.73 a
LAGRUE	59.06 a	43.60 a	96.53 a	64.13 a
N22	78.92 a	74.54 a	171.97 a	150.33 a
RONDO	20.78 a	6.88 b	19.87 a	4.20 a
ROY J	45.01 a	34.36 a	80.47 a	52.83 a
RU1601121	58.65 a	43.29 a	104.73 a	70.97 a
RU1701185	12.57 a	3.73 a	18.07 a	4.37 a
ZHE 733	67.20 a	39.69 b	117.57 a	66.40 a

[†] N22 and ZHE 733 are tolerant and susceptible checks, respectively, which were included in each batch of experiments.

[‡] Treatment means within each variety having the same letter are not significantly different according to Fisher's protected least significant difference at $\alpha = 0.05$.

Table 2. Head rice yield (HRY) and degree of endosperm chalk (DEC) of 21 selected advanced lines, varieties, and checks subjected to two night-temperature treatments: Control at 73.4 °F (23 °C) and high night temperature (HNT) at 82.4 °F (28 °C) at R2 stage (flag-leaf collar formation).

Batch	HRY		DEC	
Variety[†]	Control	HNT	Control	HNT
	----------(%)----------			
1				
11X185	59.65 a[‡]	54.96 a	7.14 b	17.65 a
19AYT57	59.85 a	56.65 a	6.14 a	14.30 a
19AYT56	63.07 a	63.32 a	8.22 a	17.65 a
CLL16	59.98	-[§]	4.65	-
DIAMOND	59.03 a	54.72 a	9.34 a	14.66 a
JEWEL	63.42 a	58.02 a	7.10 b	20.30 a
N22	56.69 a	54.95 a	22.84 a	28.13 a
RU1601010	60.67 a	56.03 b	10.49 b	36.02 a
RU1801101	62.88	59.08	6.93	7.07
RU1801145	61.72 a	59.91 a	13.52 a	15.68 a
RU1801169	64.56 a	63.95 a	5.78 a	9.38 a
ZHE 733	54.34	58.04	53.90	38.68
2				
AROMA 17	65.94 a	65.06 a	1.59 a	2.92 a
CL153	65.11	64.01	4.91	4.64
CLL15	65.83	-	6.04	-
CYPRESS	66.34 a	63.36 b	3.22 a	3.61 a
LAGRUE	59.33 a	52.33 a	9.34 b	20.15 a
N22	57.85 a	56.65 a	23.06 a	22.85 a
RONDO	60.94	-	4.48	-
ROY J	57.08 a	55.67 a	12.76 a	19.91 a
RU1601121	67.06 a	64.68 a	3.31 a	8.25 a
RU1701185	64.79	-	1.55	-
ZHE 733	51.34 a	49.98 a	54.22 a	64.84 a

[†] N22 and ZHE 733 are tolerant and susceptible checks, respectively, which were included in each batch of experiments.

[‡] Treatment means within each variety having the same letter are not significantly different according to Fisher's protected least significant difference at α = 0.05 while those having no letter suggests that mean comparison was not possible due to limited replications or missing values.

[§] Missing data.

Table 3. List of crosses, number of lines/seeds produced, current filial generation, and the type of cross developed by the high night temperature team, which can be used for selection and development of high night temperature tolerant breeding lines and or varieties.

Cross Information	No. of Lines/Seeds†	Generation	Type of Cross
CL153/N22	269	F4-F6	Single
ROY J/N22	307	F4-F6	Single
RU1601111/N22	325	F4-F6	Single
RU1601121/N22	281	F4-F6	Single
DIAMOND/N22	694	F3	Single
ZHE 733/N22	488	F3	Single
TITAN/N22	53	F3	Single
KAYBONNET/N22	(116)	F1	Single
DIAMOND//DIAMOND/N22	(23)	F1	Backcross
TITAN//TITAN/N22	(8)	F1	Backcross
KAYBONNET//DIAMOND/N22	(80)	F1	Three-way
KAYBONNET//ZHE 733 /N22	(138)	F1	Three-way

† Number inside the parenthesis refers to the number of seeds from each cross.

Genome-Wide Association Study to Identify Potential Candidate Genomic Loci Associated with Grain Yield in *Japonica* Rice under High Nighttime Temperature

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Abstract

High nighttime temperature (HNT) stress occurring during the reproductive stage of rice (*Oryza sativa* L.) causes a reduction in the number of filled grain per panicle (seed set), resulting in the loss of grain yield. Understanding the effects of HNT stress at the phenotypic and genetic levels on diverse rice accessions can provide insights into the mechanisms of grain yield decline in the field. It is therefore essential to study the natural genetic variation between and within rice subpopulations (e.g., subspecies and varieties) to utilize this resource for crop improvement. The *japonica* subspecies subpopulation is considered an underappreciated genetic resource for HNT tolerance. *Japonica,* especially tropical *japonica* (TRJ) rice, is well adapted to the Arkansas region and can be a potential gene pool for improving Arkansas rice cultivars. In this study, a panel of 81 diverse *japonica* rice accessions of the USDA Rice Mini-Core Collection (URMC) was screened for grain yield and quality components under HNT stress under controlled greenhouse conditions, and genotyped by whole genome sequencing, thereby obtaining a set of high density and good quality SNPs for a genome-wide association study (GWAS). The GWAS identified 18 highly significant associated SNPs with the number of filled grains per panicle (NFGP) under HNT stress. Out of these SNPs, 4 significant SNPs coincided with the genomic regions of previously reported QTLs related to grain yield under heat stress. These putative candidate genomic loci/or SNPs have potential use in SNP-based marker-assisted selection, QTL mapping, pyramiding of genomic regions related to grain yield, and development of HNT tolerance in Arkansas rice cultivars.

Introduction

Rice (*Oryza sativa* L.), a major staple food crop, feeds more than half of the world's population by providing 50% of the dietary calorie supply for nearly 3 billion people worldwide. In recent years, the increase in rice production attributed to the Green Revolution has slowed down, while with the rapidly increasing world population, the demands of staple food crops are increasing. Key targets to meet these demands are the development of new management techniques to boost rice production and the breeding of high-yielding rice cultivars tailored for different environments. In contrast, water scarcity and the increased frequency of extreme weather conditions are adding to the global food security challenges.

In recent years, as global temperatures are increasing, higher temperatures have led to serious yield losses and declining harvest index, especially during the flowering stage showing a reduction in grain yield of rice (Jagadish et al., 2012). The global mean surface air temperature has increased by 0.85 °C over the period from 1880 to 2012 and is predicted to increase further by 1.0–3.7 °C by the end of the 21st century, which will potentially increase the frequency and magnitude of heat stress events (IPCC, 2013). Climate change has increased nighttime temperature more than daytime temperature in rice-growing areas worldwide, and high nighttime temperature (HNT) has been attributed to the decline in grain yield and quality of rice year-by-year (Peng et al., 2004). HNT stress during the reproductive stage of rice causes poor grain filling leading to low grain yield and poor grain quality under field conditions and can be simulated under controlled conditions in the greenhouses. The sensitivity of rice to high temperatures varies with the growth stage, duration, and intensity of stress in several ways: a) vegetative- at panicle initiation; b) reproductive- from panicle initiation to grain filling; and c) ripening- from grain filling to grain maturation (Welch et al., 2010). Therefore, the available genetic variation in diverse rice accessions has to be assessed to identify favorable alleles of genes for grain yield and quality under HNT using advanced genetic techniques.

Within the rice subspecies, *indica* and *japonica*, there is a wide range of genetic variation for grain yield and quality components (Kumar et al., 2018). In the United States, the tropical *japonica* rice subspecies is widely cultivated and is represented by a high proportion of HNT tolerant accessions (Kumar et al., 2018). Therefore, quantifying the genetic variation for grain yield components and HNT tolerance in *japonica* rice is proposed to be a useful approach, where the identification of favorable alleles for grain yield components such as the number of filled grains per panicle (NFGP)/seed-set that are quantitative phenotypes. While several studies have been carried out to compare the genetic variation for heat tolerance within the *indica* and *japonica*

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rice subspecies, fewer studies have reported on quantification of genetic variation within the *japonica* rice subpopulations for their response to HNT, *japonica* rice is by itself a potential adapted gene pool to enhance rice grain yield of the U.S. rice cultivars (Kumar et al., 2018). To assess the yield components such as NFGP and quantify the genetic variation in *japonica* rice for all major effect loci, it is necessary to make a genome-wide scan such as a genome-wide association study (GWAS), to identify different favorable and unfavorable loci genome-wide for genetic selection and breeding. With the advancements in whole genome sequencing, the utilization of GWAS for mapping quantitative traits and application of the results for breeding are now common in rice. The most common approach to GWAS is to utilize a diverse population, which maximizes the diversity of alleles of useful loci, and identify a large number of potential quantitative trait nucleotides (QTNs)/SNPs associated with the target traits.

To quantify the genetic variation in *japonica* rice accessions for GWAS, we initiated a HNT screen of a panel of 81 diverse *japonica* rice accessions with similar maturity from the USDA Rice Mini-Core Collection (URMC). The objective of the study was to identify potential candidate genomic loci or SNPs associated with grain yield under HNT conditions in *japonica* rice accessions using a GWAS based mapping approach and use the SNP based markers to assist in the breeding of Arkansas rice cultivars for HNT tolerance.

Procedures

Plant Materials and HNT Stress Conditions

A panel of 81 diverse *japonica* rice accessions consisting of tropical *japonica*, temperate *japonica*, and *aromatic* accessions of the URMC were obtained from the Genetic Stocks Oryza Collection (GSOR), of the USDA-ARS Dale Bumpers National Rice Research Center, Stuttgart, AR. This *japonica* panel of the URMC was screened under HNT stress in the greenhouses in the Rosen Center at the University of Arkansas System Division of Agriculture, Fayetteville, Arkansas. Rice genotypes with panicles tagged at the R2 (booting stage) and R5 (after anthesis to grain filling) stages were placed under HNT treatment at 82.4 °F (28 °C) till harvest maturity, while controls were maintained at 71.6 °F (22°C) with the daytime temperature maintained at 86°F (30°C). Data loggers (HOBO MX2303) were installed in the greenhouses to monitor and record the temperatures throughout the growth period, which ensured continuous HNT stress during most of the flowering and harvest maturity period. At harvesting maturity (18–20% moisture), panicles were harvested, air-dried and used for recording the phenotyping data.

HNT Phenotyping and Data Analysis

Rice panicles of each accession of the panel were harvested at harvest maturity and four tagged panicles of the main stems were taken from each treatment (control and HNT stress treatments at R5 stage) for counting the number of filled grains per panicle (NFGP). For statistical analyses, the analysis of variance and full descriptive statistics were performed to analyze the genetic variation among diverse *japonica* rice accessions for grain yield components under HNT stress and control treatments, using JMP genomics and R statistical packages. The mean values of NFGP of each accession were used for GWAS mapping.

SNPs Detection and Genome-wide Marker-Trait Associations

The whole URMC sequenced by Wang et al. (2016) was made publicly available at NCBI (https://www.ncbi.nlm.nih.gov/). The genome sequence of the panel of 81 *japonica* rice accessions was downloaded and sent to the genome sequencing company Novogene (https://en.novogene.com/) for SNP calling and detection. Novogene detected 3 million (3M) SNPs from the whole genome sequences (WGS) of the 81 *japonica* rice genomes. Out of these SNPs, we filtered out a set of the best quality 204,262 SNPs showing more than 5% minor allele frequency (MAF) and less than 30% missing rate and used it for GWAS. The GWAS was performed using the Fixed and random model Circulating Probability Unification (FarmCPU) tool with multiple loci linear mixed model (MLMM) developed by Liu et al. (2016). The model uses principal components as covariates for finding the significant marker-trait associations. The association threshold was set at –log10 (p) 4.0 to detect the most significant SNPs associated with NFGP under HNT stress.

Results and Discussion

In this study, the association analysis was conducted with the FarmCPU tool using the MLMM model that incorporated multiple SNP markers simultaneously as covariates and partially removed the confounding false positives, in the panel of 81 *japonica* rice accessions for the NFGP trait with a set of 204,262 SNPs under HNT stress. The results of GWAS for NFGP in the panel of *japonica* accessions were mapped in a Manhattan plot (Fig 1A). On the quantile-quantile (Q-Q) plot of NFGP in the *japonica* panel, the observed *P*-values followed a uniform distribution and obviously deviated from the expected *P*-values distribution (Fig 1B), indicating that false positives and negatives were adequately controlled. The GWAS identified 18 highly significant SNPs associated with NFGP in the *japonica* panel under HNT stress (Table 1). These significant SNPs showing MAF that ranged from 0.071 to 0.401 and revealed a wide range of allelic effect (-39.01 to +56.883) in the panel. To validate these significant SNPs, we found co-localization of 18 significant SNPs with the genomic regions of previously reported QTLs related to grain yield in rice under heat stress. Out of these SNPs, two highly significant SNPs overlapped with the genomic regions of the previously reported QTL; *qFGP4-1* (Buu et al., 2014) related to filled grain per panicle (FGP) and grain yield (GY), and QTL *qSSP4* (Xiao et al., 2011) related to seed set percentage on chromosome 4 in the rice genome (Table 1). Interestingly, one highly significant SNP was coincident with the genomic region of *qDFT8* (Zhao et al., 2016) related to daily flowering time (DFT) on chromosome 8, while one was within the genomic region of *qDFT11* related to DFT on chromosome 11 in the rice genome (Table 1). The findings of this study corroborate independent studies for grain yield and quality components under heat stress and may be useful in the breeding of HNT stress-tolerant rice cultivars using SNP-based marker-assisted selection for Arkansas and its surrounding regions.

Practical Applications

In this study, we quantified the effects of HNT stress on the NFGP trait in *japonica* rice accessions and identified potential candidate genomic loci for SNPs associated with NFGP under HNT stress using a global GWAS approach. In the GWAS, we identified specific SNPs significantly associated with the yield component trait NFGP, which exhibited potential favorable allelic effects on grain yield components in the analysis. Furthermore, we found co-localization of the NFGP linked SNPs with previously reported QTLs related to grain yield in rice under heat stress. Therefore, the SNPs linked to the higher positive allelic effect, which co-localized with SNPs linked to previously detected QTLs, could be useful for application in the rice breeding programs using SNP-based marker-assisted selection for favorable alleles in U.S. rice cultivars with *japonica* rice background; for QTL mapping, and for further enhancement of our understanding of HNT stress mechanisms in rice.

Acknowledgments

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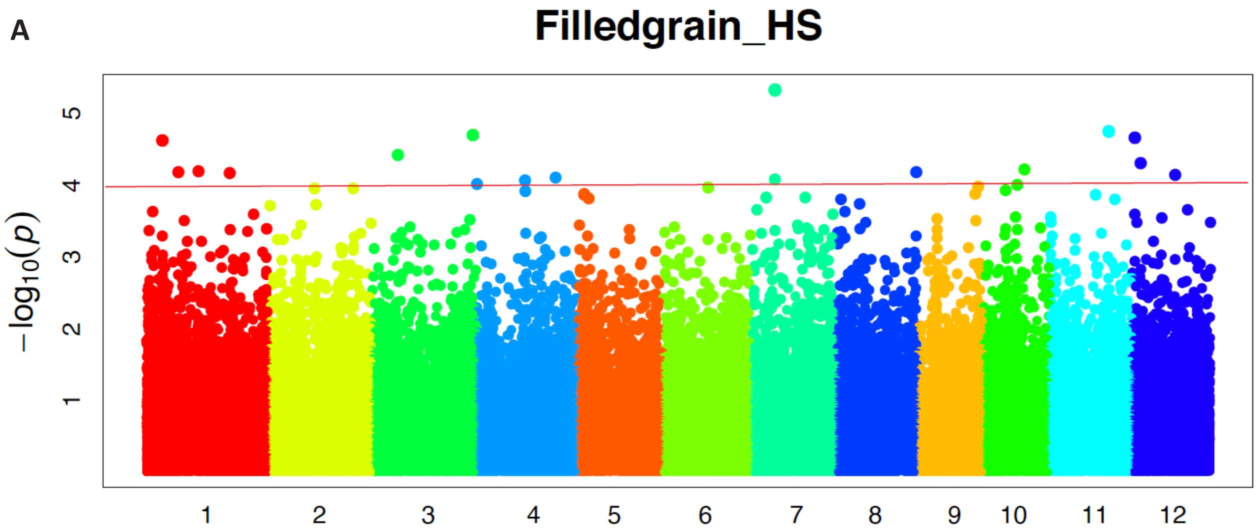
Table 1. Genome-wide significant single nucleotide polymorphisms (SNPs) associated with the number of filled grains per panicle (NFGP) in the panel of 81 *japonica* rice accessions of the USDA Rice Mini-core Collection (URMC) under high nighttime temperature (HNT) stress.

S.No.	SNP	Chr[a]	Pos[b]	MAF[c]	*P*-value	Allelic Effect	Pre Rep QTL[d]	QTL Region (bp)
1	S1_5761268	1	5,761,268	0.225	2.41E-05	29.512		
2	S1_11361640	1	11,361,640	0.316	6.51E-05	34.82		
3	S1_18396085	1	18,396,085	0.112	6.40E-05	-33.98		
4	S1_29304127	1	29,304,127	0.213	6.80E-05	-36.326		
5	S3_35255989	3	35,255,989	0.401	1.99E-05	-34.948		
6	S3_8981364	3	8,981,364	0.263	3.83E-05	-36.671		
7	S4_27864642	4	27,864,642	0.126	7.83E-05	37.873	qFGP4-1	26,857,374-34,529,916
8	S4_17082525	4	17,082,525	0.216	8.44E-05	34.853	qSSP4	15,742,285-18,824,943
9	S4_323335	4	3,23,335	0.119	9.47E-05	-30.932		
10	S7_8161744	7	8,161,744	0.112	4.72E-06	-39.01		
11	S7_8139712	7	8,139,712	0.119	8.25E-05	-31.878		
12	S8_27969998	8	27,969,998	0.274	6.49E-05	56.883	qDFT8	24,624,002-28,236,059
13	S10_14544754	10	14,544,754	0.321	6.04E-05	38.48		
14	S10_12021031	10	12,021,031	0.105	9.93E-05	41.705		
15	S11_20805149	11	20,805,149	0.135	1.76E-05	-36.859	qDFT11	17,204,553-24,661,748
16	S12_997467	12	9,97,467	0.071	2.19E-05	44.229		
17	S12_3075737	12	3,075,737	0.114	4.96E-05	40.203		
18	S12_15134028	12	15,134,028	0.205	7.13E-05	32.089		

[a] Rice Chromosome number.
[b] SNP Position in genome associated with NFGP.
[c] Minor allele frequency.
[d] Previously reported quantitative trait loci (QTLs).



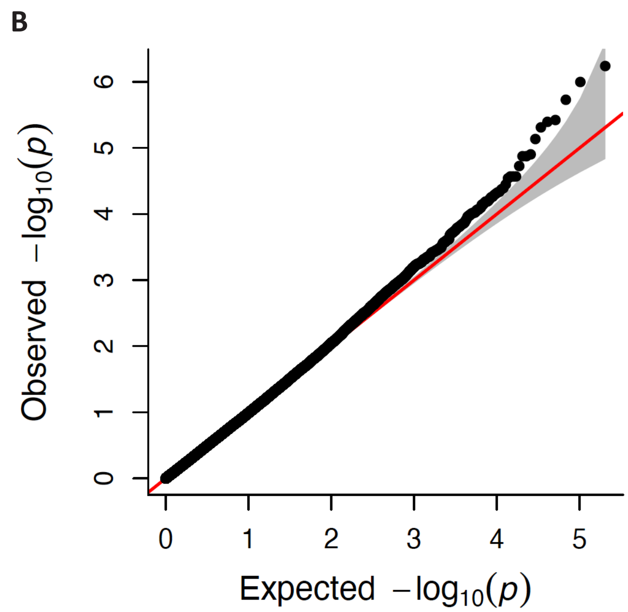


Fig. 1. Genome-wide association study (GWAS) for number of filled grains per panicle (NFGP) in a panel of 81 *japonica* rice accessions of the URMC under high nighttime temperature (HNT) stress. (A) The Manhattan plot shows significantly associated SNPs (-$\log_{10}$ > 4.0) with the NFGP trait. The horizontal black line represents the association threshold -$\log_{10}$ (4.0), and each colored dot in the plot represents a single significantly associated SNP above the threshold in the plot. (B) Quantile-quantile (Q-Q) plot of GWAS results for NFGP under (HNT) stress. The plot shows the observed *P*-values (p) for the association between NFGP and each SNP, expressed as -$\log_{10}$ of the observed *P*-values (*y*-axis) plotted against -$\log_{10}$ of the expected *P*-values (*x*-axis) under the null hypothesis of no association for the analysis.

CLL16, a new High Yielding, Clearfield, Short-Season, Long-Grain Rice Variety

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Abstract

CLL16 is a new short season, very-high yielding Clearfield, long-grain rice cultivar with the *Pi-ta* gene for blast resistance derived from the cross Wells/CL161//Taggart/3/CL172. CLL16 Breeder Head Row seed was released to BASF and Horizon Ag by the University of Arkansas System Division of Agriculture's Arkansas Agricultural Experiment Station to produce breeder and foundation seed in 2019 and 2020, respectively. The major advantages of CLL16 are its blast tolerance, very-high yield potential, high whole kernel rice milling yield, long kernel length, and low chalk. CLL16 is a non-semidwarf standard height long-grain rice cultivar with lodging resistance approaching that of Roy J. CLL16 is rated moderately resistant to narrow brown leaf spot, moderately susceptible to rice blast, false smut, and lodging, and rated susceptible to bacterial panicle blight and sheath blight.

Introduction

CLL16 was developed in the rice improvement program at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas. Breeder Head Row seed was released to BASF, who released it to Horizon Ag for seed production in 2019 and 2020. CLL16 has a very high rough rice grain yield and good milling yield. It is similar in maturity to Jewel and CL172, 4 days earlier than Roy J. CLL16 is similar in height to Diamond with canopy heights of 37 and 36 inches, respectively, and has straw strength similar to Diamond. CLL16 has the *Pi-ta* gene for blast resistance like Katy and Drew and typical U.S. long-grain cook type. CLL16 was developed with the use of rice grower check-off funds distributed by the Arkansas Rice Research and Promotion Board.

Procedures

CLL16 rice (*Oryza sativa* L.) is a very high yielding, short season, long-grain Clearfield rice cultivar developed by the Arkansas Agricultural Experiment Station. CLL16 originated from the cross Wells/CL161//Taggart/3/CL172 (cross no. 20123504), made at the RREC in 2012. The experimental designation for early evaluation of CLL16 was STG16IMI-13-016, starting with a bulk of F_5 seed from the 2016 panicle row IMI-13-016. CLL16 was tested in the Arkansas Rice Performance Trials (ARPT) and the Cooperative Uniform Regional Rice Nursery (URRN) during 2018–2019 as entry RU1901041 [RU number indicated Cooperative Uniform Regional Rice Nursery (URRN); 19 indicates year entered was 2019; 01 indicates Stuttgart, Arkansas; and 041 its entry number] and as CLXAR19 for Clearfield experimental from Arkansas, for potential release in 2019.

In 2018 and 2020, the ARPT was conducted at five locations in Arkansas: RREC; University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Keiser, Ark.; the Pine Tree Research Station (PTRS), near Colt, Ark.; the Bowers Farm, Clay County (BFCC) near Corning Ark.; and the Whitaker Farm, Chicot County (WFCC) near Dumas, Ark; in 2019 the trials were grown at RREC, NEREC, PTRS, and BFCC. The tests had four replications per location to reduce soil heterogeneity effects and to decrease the amount of experimental error. CLL16 was also grown in the URRN at the RREC; Crowley, Louisiana; Stoneville, Mississippi; Beaumont, Texas; and at Malden Missouri 2018–2020. This test has three replications per location. Data collected from the ARPT and URRN tests included plant height, maturity, lodging, percent head rice, percent total rice, and grain yield adjusted to 12% moisture and disease reaction information. Cultural practices varied somewhat among locations, but overall the trials were grown under conditions of high productivity as recommended by the University of Arkansas System Division of Agriculture's Cooperative Extension Service Rice Production Handbook MP192 (CES, 2018). Agronomic and milling data are presented in Tables 1 and 2. Disease ratings, which are indications of potential damage under conditions favorable for the development of specific diseases, have been reported on a scale from 0 = least susceptible to 9 = most susceptible, or as very susceptible (VS), susceptible (S), moderately susceptible (MS), moderately resistant (MR) and resistant (R), respectively. Straw strength is a relative estimate based on observations of lodging in field tests using the

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scale from 0 = very strong straw to 9 = very weak straw, totally lodged.

Results and Discussion

Rough rice grain yields of CLL16 have compared favorably with CLL15 and Diamond in the ARPT. In 14 ARPT tests (2018–2020), CLL16, CLL15, Jewel, and Diamond averaged yields of 204, 199, 185, and 205, bu./ac, respectively (Table 1). Data from the URRN conducted at Arkansas during 2019–2020 showed that CLL16 average grain yield of 214 compared to CLL15, Jewel, and Diamond at 187, 216, and 225, respectively (Table 2). Milling yields (%whole kernel:% total milled rice) at 12% moisture from the ARPT, 2018–2020, averaged 55:70, 59:70, 60,70, and 57:71, for CLL16, CLL15, Jewel, and Diamond, respectively. Milling yields for the URRN in Arkansas, 2019–2020, averaged 58:70, 62:70, 60:71, and 59:70, for CLL16, CLL15, Jewel, and Diamond, respectively.

CLL16 is a short-season variety close to the maturity of Jewel and about 4 to 5 days later than CLL15. CLL16, like Jewel and Diamond, has good straw strength, which is an indicator of lodging resistance. On a relative straw strength scale based on field tests, CLL16 rated 1.1 compared to Jewel and Diamond, which rated 1.0, and 1.0, respectively. CLL16, like Jewel and Diamond, has an average canopy height of 37 inches and when measured to the tip of the panicle, 44 inches.

CLL16 has the genes *Pi-ta* and *Pi-km* and, like Jewel, Katy, and Drew, is resistant to common rice blast (*Pyricularia grisea* (Cooke) Sacc.) races IB-1, IB-17, IB-49, IC-17, and IE-1, with summary ratings in greenhouse tests of 0, 0, 0, 0 and 0, respectively, while it rates a 6 to race IE-1K using the standard disease scale of 0 = immune, 9 = maximum disease susceptibility. CLL16 is rated S to sheath blight (*Rhizoctonia solani* Kühn) which compares with CLL15 (S), Diamond (S), Jewel (MS), LaKast (MS), and Wells (S) using standard disease R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible and VS = very susceptible to disease. CLL16 is rated MS for false smut [*Ustilaginoidea virens* (Cooke) Takah] compared to CLL15 (S), Diamond (VS), and Jewel (MS). CLL16 is rated S to bacterial panicle blight caused by *Burkholderia species* compared to CLL15 (S), Jewel (MR), and Diamond (MS).

Plants of CLL16 have erect culms, erect green leaves, and glabrous lemma, palea, and leaf blades. The lemma and palea are straw-colored with tawny apiculi, most of which fade to straw at maturity. Milled kernels of CLL16 are 7.23 mm in length compared to CLL15, Diamond, and Jewel at 7.09, 7.16, and 7.06 mm, respectively. Individual milled kernel weights of CLL16, CLL15, Diamond, and Jewel averaged 22.2, 20.0, 21.3, and 19.8 mg/kernel, respectively, from the ARPT 2018–2019 data from the Riceland Foods Inc. Quality Laboratory.

The endosperm of CLL16 is non-glutinous, nonaromatic, and covered by a light brown pericarp. Rice quality parameters indicate that CLL16 has typical Southern U.S. long-grain cooking quality characteristics as described by Webb et al. 1985. CLL16 has an average apparent starch amylose content of 23.6% compared to CLL15, Diamond, and Jewel at 22.0%, 22.4%, and 25.3%, respectively, and an intermediate gelatinization temperature of 69.6 °C compared to CLL15, Diamond, and Jewel at 70.4 °C, 70.2 °C, and 71.3 °C, respectively, as measured by the Riceland Food Inc Quality Laboratory 2018–2019.

Practical Applications

The release of CLL16 provides producers with a very high yielding, short season, long-grain Clearfield rice, which has the *Pi-ta* gene that confers resistance to the common blast races in Arkansas and typical Southern U.S. cooking quality.

Acknowledgments

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Table 1. Three-year average for yield and three-year average for the agronomic data from the 2018 to 2020 University of Arkansas System Division of Agriculture's Arkansas Rice Performance Trials for CLL16 and other cultivars.

Cultivar	Grain Type[a]	Yield[b] 2018	2019	2020	Mean	Height[c]	50% Heading	Chalky Kernels[d]	Milling[e]
		-----------------------bu./ac	-----------------------			(in.)	(days)	(%)	%HR/%TR
CLL16	L	207	205	200	204	37	85	1.91	55/70
CLL15	L	192	206	200	199	32	83	1.34	59/71
Jewel	L	186	184	186	185	37	85	1.82	60/70
Diamond	L	206	204	206	205	36	83	1.91	57/71

[a] Grain type L = long grain.

[b] Yield trials in 2018 and 2020 consisted of five locations, University of Arkansas System Division of Agriculture's Rice Research and Extension Center, (RREC), Stuttgart Arkansas; Pine Tree Research Station, (PTRS), Colt, Arkansas; Northeast Research and Extension Center, (NEREC), Keiser, Arkansas; Bowers Farm, Clay County, (BFCC), Corning, Arkansas; and Whitaker Farm, Chicot County, (WFCC), Dumas, Arkansas. In 2019, the successful trials were grown at RREC, PTRS, NEREC, and BFCC.

[c] Height data is canopy height from 2018–2020.

[d] Data for chalk is from 2017–2019 Riceland Foods Inc. Grain Quality Laboratory data.

[e] Milling figures are percent head rice/percent total milled rice 2018–2020.

Table 2. Data from the 2019 to 2020 Uniform Regional Rice Nursery (URRN) for CLL16 and other check cultivars.

Cultivar	Yield[a] 2019	2020	Mean	Arkansas Yield[b] 2019	2020	Mean	Height[c]	50% Heading[d]	Milling[e]
	-------------bu./ac	-------------		-------------bu./ac	-------------		(in.)	(days)	%HR/%TR
CLL16	215	214	215	223	204	214	44	94	58/70
CLL15	179	182	181	209	165	187	39	88	62/70
Jewel	202	207	205	245	186	216	42	92	60/71
Diamond	198	211	205	253	196	225	44	91	59/70

[a] AR = Rice Research and Extension Center, Stuttgart, Arkansas; LA = Rice Research Station Crowley, Louisiana; MO = Malden, Missouri; MS = Stoneville, Mississippi; and TX = Texas A&M, Beaumont Texas.

[b] Arkansas URRN yields.

[c] Height data height from ground to panicle tip AR 2019–2020 only.

[d] Heading data from AR 2019–2020 only.

[e] Milling figures are percent head rice/percent total milled rice data from AR 2019–2020.

Evaluation of Advanced Medium-Grain and Long-Grain Breeding Lines at Three Arkansas Locations

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Abstract

For rice breeders to identify the ideal breeding lines for potential varietal releases, it is critical to have a yield trial under the most representative soil types and environmental conditions. To bridge the gap between the single location, 2-replication preliminary yield trials and the multi-state Cooperative Uniform Regional Rice Nursery (URRN) and/or the multi-location statewide Arkansas Rice Performance Trial (ARPT), which only accommodate a very limited number of entries, an advanced elite line yield trial (AYT) was initiated in 2015. The trial is conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), near Stuttgart, Arkansas; the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), near Colt, Arkansas; and the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), in Keiser, Arkansas. This trial will help us to select the best and most uniform breeding lines for advancement into the URRN and/or ARPT trials, and ultimately will improve the quality of those yield trials.

Introduction

Complicated rice traits, such as yield and quality, can only be evaluated effectively in replicated yield trials. Once reaching a reasonable uniformity, rice breeding lines are bulk-harvested and tested in a single location, 2-replication preliminary yield trials, which include the Clearfield® (CL) Stuttgart Initial Trial (CSIT), Provisia® (PV) Stuttgart Initial Trial (PSIT) or Conventional Stuttgart Initial Trial (SIT). Each year, about 1,200 new breeding lines are tested in CSIT, PSIT, or SIT trials. About 10% of the tested breeding lines, which are expected to yield statistically or numerically higher than commercial checks and possess desirable agronomical characteristics, need to be tested in replicated and multi-location advanced yield trials. However, the current advanced yield trials include the multi-state Uniform Regional Rice Nursery (URRN) and statewide Arkansas Rice Performance Trial (ARPT) that only accommodate about 20 entries from each of the three breeders each year. Obviously, a new replicated and multi-location trial is needed to accommodate those additional breeding lines. In addition to the validation of the findings in the previous preliminary trials, the new trial will result in purer and more uniform seed stock for URRN and ARPT trials.

Procedures

A total of 80 entries were tested in 2020 AYT trial, which included 68 experimental inbred lines (24 CL long-grain, 12 CL medium-grain, 1 CL Jasmine-type long-grain, 16 conventional long-grain, and 15 conventional medium-grain), 2 experimental long-grain hybrids, and 10 commercial check varieties. Twenty-two of the experimental lines were also concurrently tested in 2020 URRN and/or ARPT trials. The experimental design for all three locations is a randomized complete block with three replications. Plots measuring 4.38 feet wide (7 rows with a 7.5-in. row spacing) and 14.25 feet long were drill-seeded at 95 pounds per acre rate. All seeds were treated with AV-1011 (18.3 fl oz/cwt) and CruiserMaxx Rice (7 fl oz/cwt) for blackbird and insect pests, respectively. The soil types at NEREC, PTRS, and RREC are Sharkey clay, Calloway silt loam, and DeWitt silt loam, respectively. Planting dates at NEREC, PTRS, and RREC were 21 May, 21 April, and 16 April, respectively. A single pre-flood application of 145-pound nitrogen in the form of urea was applied to a dry soil surface at the 4- to 5-leaf stage, and a permanent flood was established 1–2 days later. At maturity, the six rows (including a border row) of each plot were harvested by using a Wintersteiger plot combine (Wintersteiger AG, 4910 Ried, Austria), and the moisture content and plot weight were determined by the automated weighing system Harvest Master that is integrated into the combine. A small sample of seed was collected from the combine for each plot for later milling yield determination. Due to severe lodging caused by hurricane Laura, a number of plots were abandoned, and no milling sample was collected at the RREC location. Milling evaluations of the NEREC location were conducted by Riceland Foods, Inc. (Stuttgart, Ark.), while that of the PTRS location were conducted in-house on a Zaccaria PAZ-100 sample mill (Zaccaria, Limeira, Brazil). Grain yields were calculated as bushel per acre at 12% moisture content.

Data were analyzed using the General Linear Model procedure of SAS software, v. 9.4 (SAS Institute, Cary, N.C.). Analysis of variance for grain yield, milling yields, days to 50% heading, plant height, and seedling vigor was performed for each location, and a combined analysis was conducted across locations.

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[3] Resident Director in Charge, Northeast Research and Extension Center, Keiser.

The means were separated by Fisher's protected least square difference (LSD) test at the 0.05 probability level. No statistical analysis was conducted for grain yield at the RREC location due to numerous missing data.

Results and Discussion

The average grain yield of all entries across 2 locations is 220 bushel per acre (bu./ac) (Table 1), which is higher than the 195 and 199 bu./ac average in 2019 and 2018, respectively. NEREC has an average yield of 225 bu./ac as compared with 214 bu./ac of PTRS. Overall, medium-grain rice outperformed long-grain rice for both grain and milling yields. The top 5 highest yielding entries are commercial hybrids RT7521 FP and XL753, followed by experimental long-grain hybrid 20AYT12 (RU2001211) and CL medium-grain lines 20AYT43 (RU1901137) and 20AYT27 with the average grain yield of 261, 258, 255, 242, and 240 bu./ac, respectively. The average milled head rice and total rice across locations are 66% and 71% (Table 2), higher than 62% and 71% in 2019, respectively. The average seedling vigor is 3.4, which is similar to the 3.3 of 2019; the average days to 50% heading is 84 days; and the average plant height is 40 inches.

Nine conventional medium-grain lines out-yielded Jupiter and Titan, while four of them also yielded higher than newly released Lynx that has the highest grain yield among all medium-grain checks. These 4 experimental medium-grain lines are 20AYT60, 20AYT63, 20AYT52, and 20AYT69 (RU1801237) with an average yield of 238, 237, 236, and 236 bu./ac, respectively. Meanwhile, four CL medium-grain lines have a higher grain yield than both Jupiter and CLM04, which include 20AYT43 (RU1901137), 20AYT27, 20AYT22, and 20AYT37 with an average yield of 242, 240, 232, and 230 bu./ac, respectively. Sixteen CL long-grain experimental lines outperformed both CLL15 and CLL16, and among them 20AYT53 (RU2001121) has an average yield of 235 bu./ac that is significantly ($P < 0.05$) higher than 208 bu./ac of CLL16. Six experimental long-grain lines, including 20AYT77 (RU2001185), 20AYT66 (RU2011169), 20AYT56, 20AYT73, 20AYT72 (RU2001137), and 20AYT51 yielded higher than Diamond with an average yield of 237, 227, 225, 225, 224, 224, and 224 bu./ac, respectively, as compared with 223 bu./ac of Dimond. Most of these top-yielding experimental lines will be advanced to or re-tested in the 2021 on-farm Commercial Cultivar Trial (CRT), ARPT, and/or URRN trials.

Practical Applications

The new AYT trial successfully bridged the gap between the single location preliminary yield trials with numerous entries and the multi-state or statewide advanced yield trial that can only accommodate a very limited number of entries by offering opportunities for the trial of additional elite breeding lines. Our results enable us to confirm the findings from other yield trials and to identify the outstanding breeding lines, which otherwise were excluded from URRN or ARPT trials due to insufficient space.

Acknowledgments

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Table 1. Grain yield of 80 long- and medium-grain breeding lines and commercial checks in the advanced elite line yield trial (AYT) conducted at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) at Keiser, Arkansas, Pine Tree Research Station (PTRS) near Colt, Arkansas, and Rice Research and Extension Center (RREC) near Stuttgart, Arkansas, 2020.

			Grain Yield			
Entry	Pedigree	GT[a]	NEREC	PTRS	RREC	Mean[b]
			-----------------(bu./ac)----------------			
20AYT01	CLL15	CL	200	190	152	195
20AYT02	CL153	CL	192	217	158	205
20AYT03	CLL16	CL	208	208	200	208
20AYT04	CLM04	CM	215	224	183	220
20AYT05	Jupiter	M	231	219	173	225
20AYT06	Titan	M	215	206	163	210
20AYT07	Lynx	M	235	230	212	232
20AYT08	Diamond	L	241	205	197	223
20AYT09	XP753	L(H)	263	252	234	258
20AYT10	RT7521 FP	L(H)	266	255	256	261
20AYT11	805S/RU1701185	L(H)	231	240	195	236
20AYT12	811S/RU1701185	L(H)	291	219	213	255
20AYT13	NPTN/08-81984//CL261	CM	192	172	172	182
20AYT14	RU1102034/RU1501024*2	CL	218	188	186	203
20AYT15	FRNS/RU1501024	CL	222	211	199	216
20AYT16	RU1102131/CL172	CL	228	201	193	215
20AYT17	TGRT/CL111	CL	209	204	157	206
20AYT18	CL172/RU1102034	CL	242	217	168	229
20AYT19	RU0902028/STG10IMI-05-034	CL	212	203	157	208
20AYT20	RU1202131/RU1401044	CL	214	194	150	204
20AYT21	9902028/3/BNGL//MERC/RICO/4/RU1202068	CM	219	212	161	215
20AYT22	RICO/BNGL//RU1202068	CM	232	231	175	232
20AYT23	CFFY/RU1202168	CM	211	200	186	205
20AYT24	RU1102131/RU1302045	CL	218	198	146	208
20AYT25	JSMN/DLLA//DLLA/3/JZMN/4/RU1201025	CLJ	220	191	176	206
20AYT26	CFFY/CL261	CM	202	218	174	210
20AYT27	14SIT818/RU1501096	CM	236	243	n/a	240
20AYT28	14SIT818/14CSIT314	CM	189	224	166	207
20AYT29	RU1302048/CL151	CL	226	206	181	216
20AYT30	RU1102034/RU1501024*2	CL	235	219	145	227
20AYT31	ROYJ/RU1501024	CL	227	187	181	207
20AYT32	ROYJ/14CSIT203	CL	223	219	166	221
20AYT33	CTHL/CL172	CL	209	197	163	203
20AYT34	DMND/RU1501164	CL	231	217	n/a	224
20AYT35	ROYJ/RU1501024	CL	237	211	214	224
20AYT36	ROYJ/RU1501024	CL	218	216	166	217
20AYT37	NPTN/RU1501096	CM	226	234	184	230
20AYT38	RU1102131/14CSIT203	CL	215	212	163	213
20AYT39	16AYT045/RU1201136	CL	234	217	172	225
20AYT40	DMND/RU1501185	CL	207	209	206	208
20AYT41	DMND/CL172	CL	232	194	164	213

Continued

Table 1. Continued.

Entry	Pedigree	GT[a]	Grain Yield NEREC	PTRS	RREC	Mean[b]
			------------------bu./ac-----------------			
20AYT42	CL153/CL172	CL	230	208	154	219
20AYT43	CL271/JPTR	CM	241	243	185	242
20AYT44	EARL/9902028//RU1202068	CM	218	216	194	217
20AYT45	EARL/9902028//RU1202068	CM	236	203	203	219
20AYT46	RU1701124/15CSIT769	CM	214	200	190	207
20AYT47	ROYJ/RU1102034	L	196	179	173	187
20AYT48	ROYJ*2/RU1401133	CL	194	194	172	194
20AYT49	JPTR/RU0401084	M	218	213	184	215
20AYT50	ROYJ/RU1202131	L	219	202	n/a	210
20AYT51	MRMT/LKST	L	244	204	180	224
20AYT52	TITN/07SP301	M	241	231	188	236
20AYT53	RU1102131/14CSIT203	CL	232	237	157	235
20AYT54	07SP296/07SP308	M	211	219	n/a	215
20AYT55	RU1102131/CL172	CL	222	216	178	219
20AYT56	RU0902125/RU1102034	L	238	212	190	225
20AYT57	RU1102034/LKST	L	235	212	166	223
20AYT58	07SP308/NPTN	M	243	204	182	223
20AYT59	07SP308/RU0401084	M	225	209	176	217
20AYT60	07SP308/RU0502137	M	244	231	194	238
20AYT61	RICO/BNGL//CFFY	M	240	221	188	230
20AYT62	RU0401064/TITN	M	221	223	220	222
20AYT63	JPTR//EARL/9902028	M	242	231	185	237
20AYT64	RU1102034/RU1201108	L	202	210	174	206
20AYT65	ROYJ/RU1501127	L	224	197	172	210
20AYT66	ROYJ/RU1501127	L	235	218	178	227
20AYT67	CFFY/14SIT891	M	227	225	222	226
20AYT68	RU1102131/RU0801093	L	229	216	185	222
20AYT69	JPTR/EARL	M	244	227	177	236
20AYT70	JPTR/J062	M	226	219	191	223
20AYT71	ROYJ/RU1102034	L	235	207	193	221
20AYT72	RU1301121/TITN	M	234	215	174	224
20AYT73	NPTN/07PY828	M	225	225	n/a	225
20AYT74	EARL/JPTR	M	205	220	n/a	213
20AYT75	RU1102034/DMND	L	232	205	175	219
20AYT76	RICO/BNGL//RU0602162/RU0502031	M	235	221	n/a	228
20AYT77	JPTR/3/EARL//BNGL/SHORTRICO	M	246	229	n/a	237
20AYT78	RU1001067/JPTR	M	198	197	166	198
20AYT79	RU1001067/RU0602171	M	235	218	205	226
20AYT80	CFFY/RU1202068	CM	217	233	193	225
C.V.(%)[c]			8.6	9.2		9.2
$LSD_{0.05}$			31	32		23

[a] Grain type, CL = Clearfield long-grain, CM = Clearfield medium-grain, L = conventional long-grain, L(H) = long-grain hybrid, and M = conventional medium-grain.
[b] NEREC and PTRS locations only.
[c] Coefficient of variance.

Table 2. Average seedling vigor (SV), days to 50% heading (HD), plant height (HGT), and milling yields (MY, % head rice/% total rice) of 2020 advanced elite line yield trial (AYT) conducted at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) at Keiser, Arkansas, Pine Tree Research Station (PTRS) near Colt, Arkansas, and Rice Research and Extension Center (RREC) near Stuttgart, Arkansas.

Entry	Pedigree	GT[a]	SV[b]	HD	HGT	%HR/%TR[c]
					(in.)	
20AYT01	CLL15	CL	3.0	84	36	65/69
20AYT02	CL153	CL	3.0	85	38	67/71
20AYT03	CLL16	CL	3.0	88	41	63/69
20AYT04	CLM04	CM	3.0	85	40	68/71
20AYT05	Jupiter	M	3.0	85	37	68/70
20AYT06	Titan	M	3.0	80	38	68/71
20AYT07	Lynx	M	3.3	84	39	68/71
20AYT08	Diamond	L	3.0	85	43	65/70
20AYT09	XP753	L(H)	4.0	82	44	63/71
20AYT10	RT7521 FP	L(H)	4.0	84	46	65/71
20AYT11	805S/RU1701185	L(H)	4.7	85	50	65/71
20AYT12	811S/RU1701185	L(H)	4.7	83	50	63/70
20AYT13	NPTN/08-81984//CL261	CM	3.0	83	36	68/71
20AYT14	RU1102034/RU1501024*2	CL	3.0	83	41	68/72
20AYT15	FRNS/RU1501024	CL	3.7	83	39	66/71
20AYT16	RU1102131/CL172	CL	3.3	85	38	66/71
20AYT17	TGRT/CL111	CL	3.0	85	40	65/71
20AYT18	CL172/RU1102034	CL	3.3	86	41	67/71
20AYT19	RU0902028/STG10IMI-05-034	CL	3.0	83	39	68/72
20AYT20	RU1202131/RU1401044	CL	3.0	83	38	68/72
20AYT21	9902028/3/BNGL//MERC/RICO/4/RU1202068	CM	3.0	84	39	67/72
20AYT22	RICO/BNGL//RU1202068	CM	3.3	83	37	66/71
20AYT23	CFFY/RU1202168	CM	4.0	85	35	68/73
20AYT24	RU1102131/RU1302045	CL	3.0	86	39	67/71
20AYT25	JSMN/DLLA//DLLA/3/JZMN/4/RU1201025	CLJ	3.7	87	40	66/70
20AYT26	CFFY/CL261	CM	3.7	86	37	68/71
20AYT27	14SIT818/RU1501096	CM	4.0	84	39	66/70
20AYT28	14SIT818/14CSIT314	CM	3.0	80	41	66/71
20AYT29	RU1302048/CL151	CL	4.0	81	40	65/70
20AYT30	RU1102034/RU1501024*2	CL	3.0	84	40	68/72
20AYT31	ROYJ/RU1501024	CL	3.7	84	38	64/70
20AYT32	ROYJ/14CSIT203	CL	3.3	85	40	67/71
20AYT33	CTHL/CL172	CL	3.7	87	37	68/72
20AYT34	DMND/RU1501164	CL	3.0	83	42	64/71
20AYT35	ROYJ/RU1501024	CL	3.0	84	41	65/70
20AYT36	ROYJ/RU1501024	CL	3.0	87	39	67/71
20AYT37	NPTN/RU1501096	CM	4.0	86	37	68/70
20AYT38	RU1102131/14CSIT203	CL	3.3	85	37	67/72
20AYT39	16AYT045/RU1201136	CL	3.0	85	42	67/72
20AYT40	DMND/RU1501185	CL	3.7	85	41	66/72
20AYT41	DMND/CL172	CL	3.0	84	39	66/71
20AYT42	CL153/CL172	CL	4.0	86	38	67/71

Continued

Table 2. Continued.

Entry	Pedigree	GT[a]	SV[b]	HD	HGT	%HR/%TR[c]
					(in.)	
20AYT43	CL271/JPTR	CM	4.0	87	37	68/72
20AYT44	EARL/9902028//RU1202068	CM	3.7	85	39	68/72
20AYT45	EARL/9902028//RU1202068	CM	3.0	84	38	67/72
20AYT46	RU1701124/15CSIT769	CM	4.0	80	41	67/71
20AYT47	ROYJ/RU1102034	L	3.3	87	40	68/72
20AYT48	ROYJ*2/RU1401133	CL	3.3	85	46	66/72
20AYT49	JPTR/RU0401084	M	3.7	85	39	69/71
20AYT50	ROYJ/RU1202131	L	3.3	84	44	65/72
20AYT51	MRMT/LKST	L	3.0	83	38	66/71
20AYT52	TITN/07SP301	M	3.0	83	36	68/71
20AYT53	RU1102131/14CSIT203	CL	3.7	84	39	69/73
20AYT54	07SP296/07SP308	M	3.7	82	37	69/72
20AYT55	RU1102131/CL172	CL	3.0	85	36	69/73
20AYT56	RU0902125/RU1102034	L	3.3	83	37	69/72
20AYT57	RU1102034/LKST	L	3.3	85	38	67/72
20AYT58	07SP308/NPTN	M	3.0	82	35	69/73
20AYT59	07SP308/RU0401084	M	4.0	76	36	69/72
20AYT60	07SP308/RU0502137	M	3.7	83	39	67/71
20AYT61	RICO/BNGL//CFFY	M	4.0	80	36	69/71
20AYT62	RU0401064/TITN	M	3.7	83	38	69/71
20AYT63	JPTR//EARL/9902028	M	3.7	84	39	68/70
20AYT64	RU1102034/RU1201108	L	3.3	85	43	66/71
20AYT65	ROYJ/RU1501127	L	3.7	86	43	65/70
20AYT66	ROYJ/RU1501127	L	4.0	87	42	65/70
20AYT67	CFFY/14SIT891	M	3.7	85	38	68/71
20AYT68	RU1102131/RU0801093	L	3.3	85	43	67/72
20AYT69	JPTR/EARL	M	4.0	84	36	69/71
20AYT70	JPTR/J062	M	4.0	84	38	69/71
20AYT71	RU1002128/DMND	L	3.3	86	41	66/71
20AYT72	MRMT/RU1401142	L	4.0	85	39	67/71
20AYT73	MRMT/RU1201136	L	3.0	87	40	67/71
20AYT74	DMND/LKST	L	3.3	84	44	65/71
20AYT75	FRNS/TGRT	L	3.7	86	43	66/72
20AYT76	RICO/BNGL//RU0602162/RU0502031	M	3.0	81	35	68/71
20AYT77	DMND/LKST	L	4.0	84	43	67/71
20AYT78	FRNS/TGRT	L	3.3	87	40	66/71
20AYT79	RU1001067/RU0602171	M	3.0	84	35	68/71
20AYT80	JPTR/J062	M	3.3	84	38	68/71
C.V.(%)[d]			10.8	1.6	5.4	1.4/0.8
$LSD_{0.05}$			0.6	1.3	2.0	1.1/0.6

[a] Grain type, CL = Clearfield® long-grain, CM = Clearfield® medium-grain, L = conventional long-grain, L(H) = long-grain hybrid, and M = conventional medium-grain.

[b] A subjective rating 1–7 taken at emergence, 1 = excellent stand and 7 = no stand.

[c] Milling yield, HR = head rice and TR = total rice yield.

[d] Coefficient of variance.

Development of Superior Medium-Grain and Long-Grain Rice Varieties for Arkansas and the Mid-South

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Abstract

Reflecting recent changes of Arkansas rice industry and streamline the delivery of new and improved rice varieties to Arkansas rice growers, the medium-grain rice breeding project has expanded its research areas and breeding populations to include conventional, Clearfield®, and Provisia® medium-grain and long-grain rice as well as hybrid rice. The newest elite breeding lines/varieties from collaborating programs, as well as lines with diverse genetic origins, will be actively collected, evaluated, and incorporated into current crossing blocks for programmed hybridization. Maximum mechanized-operation, multiple generations grown in the winter nursery, and new technologies such as molecular marker-assisted selection (MAS) and genomic selection are rigorously pursued to improve the efficiency and effectiveness of the program.

Introduction

Medium-grain rice is an important component of Arkansas rice. Arkansas ranks second in medium-grain rice production in the United States, only behind California. During 2010–2019, an average of 0.18 million acres of medium-grain rice was grown annually, making up about 13% of total state rice acreage (USDA-ERS, 2020). A significant portion of the Arkansas rice area was planted to semi-dwarf long-grain varieties, such as CLL15, CL151, CL153, and Cheniere. Locally developed varieties for Arkansas offer advantages, including better stress tolerance and more stable yields. Improved semi-dwarf long-grain lines can also be directly adopted by the newly established hybrid breeding program. Since genetic potential still exists for further improvement of current varieties, rice breeding efforts must continue to maximize yield and quality for the future.

The inter-subspecies hybrids between *indica* male sterile lines and tropical *japonica* restorer/pollinator lines, which were first commercialized in the United States in 1999 by RiceTec, have a great yield advantage over conventional pure line varieties (Walton, 2003). However, further improvement of hybrid rice is critically needed to address its inconsistent milling yield, poor grain quality, lodging susceptibility, pubescent leaf and sheath, volunteer weedy rice out of dormant residue seeds, and high seed cost. A public hybrid rice research program that focuses on the development of adapted lines (male sterile, maintainer, and restorer lines) will be instrumental in overcoming such constraints.

Procedures

Potential parents for the breeding program are evaluated for the desired traits. Cross combinations are programmed that combine desired characteristics to fulfill the breeding objectives. Marker-assisted selection (MAS) will be carried out on backcross or topcross progenies for simply inherited traits such as herbicide resistance, blast resistance, and physicochemical characteristics. Segregating populations are planted, selected, and advanced at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas, and the winter nursery near Lajas, Puerto Rico. Pedigree and modified single-seed descent will be the primary selection methodologies employed. A great number of traits will be considered during this stage of selection, including grain quality (shape and appearance), plant type, short stature, lodging resistance, disease (blast, sheath blight, and panicle blight) resistance, earliness, and seedling vigor. Promising lines with a good combination of these characteristics will be further screened in the laboratory for traits such as kernel size and shape, grain chalkiness, and grain uniformity. Milling evaluation of small size samples, as well as physicochemical analysis by Riceland Foods Research and Technology Center, will be conducted to eliminate lines with evident quality problems in order to maintain the standard U.S. rice quality of different grain types/market classes. Yield evaluations include the Stuttgart Initial Yield Trial (SIT), Clearfield® SIT (CSIT), and Provisia® SIT (PSIT) at RREC, the Advanced Elite Line Yield Trial (AYT), Clearfield® AYT (CAYT), and Provisia® AYT (PAYT) at RREC, Pine Tree Research Station (PTRS) near Colt, Arkansas, and Northeast Research and Extension Center (NEREC) in Keiser, Arkansas Advanced yield testing includes the Arkansas Rice Performance Trials (ARPT) and on-farm Commercial Cultivar Testing (CRT) conducted by Dr. Jarrod Hardke, the Arkansas rice agronomy specialist, at 6–10 locations in rice-growing regions across the state, and the Uniform Regional Rice Nursery (URRN) conducted

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in cooperation with public rice breeding programs in California, Louisiana, Mississippi, Missouri, and Texas. Promising advanced lines will be further evaluated in the new Pre-commercial (PC) trial conducted at 30 locations in Arkansas, Louisiana, and Texas, as well as by cooperating projects for their resistance to sheath blight, blast, and panicle blight, grain and cooking/processing quality, and nitrogen fertilizer requirements. All lines entered in the SIT, CSIT, or PSIT and beyond will be planted as head rows for purification and increase purposes.

Results and Discussion

A great number of breeding populations have been created and rapidly advanced since 2013, shortly after the senior author was hired. The field research in 2020 included 1,348 transplanted or drill-seeded F_1 populations, 994 space-planted F_2 populations, and 61,500 panicle rows ranging from F_3 to F_7. Visual selection on approximate 800,000 individual space-planted F_2 plants resulted in a total of 40,000 panicles that will be individually processed and grown as F_3 panicle rows in 2021. A total of 4,383 panicle rows were selected for advancement to the next generation; while 1,400 rows appeared to be uniform and superior to others and therefore were bulk-harvested by hand as candidates of 2021 SIT, CSIT, and PSIT trials. In 2020 CSIT, we evaluated 549 new breeding lines, which included 425 CL long-grain, 123 CL medium-grain, and 1 CL jasmine-type aromatic long-grain lines. Of 579 new conventional breeding lines tested in the SIT trial, 454 were long-grain lines,124 medium-grain lines, and 1 short-grain line. Molecular marker-assisted selection (MAS) was conducted on 968 samples including preliminary yield trial entries and PVbackcrosses or 3-way crosses by using 10 SSR and SNP molecular markers for physicochemical characteristics, blast resistance, and herbicide resistance. A number of breeding lines in both SIT and CSIT trials showed yield potential similar to or better than the check varieties (Tables 1–4), and will be evaluated in advanced yield trials in 2021. Twenty advanced experimental lines were evaluated in the multi-state URRN and statewide ARPT and CRT trials. Results of those entries and selected check varieties are listed in Table 5. Three Puerto Rico winter nurseries consisting of 13,600 7-foot rows were planted, selected, and turned around during offseason 2020, and will be harvested in spring 2021. A total of 1,119 new single crosses and backcrosses were made to incorporate desirable traits from multiple sources into adapted Arkansas rice genotypes, which included 194 CL long-grain, 79 CL medium-grain, 343 conventional long-grain, 66 conventional medium-grain, 403 PV long-grain, and 31 PV medium-grain crosses. We also made 351 testcrosses and backcrosses for the hybrid rice breeding.

The conventional medium-grain variety Lynx has continuously performed well in 2020 trials. Certified/registered seeds should be readily available to rice growers for the 2021 season. Breeder headrow and/or breeder seed production of conventional long-grain line RU2001185, conventional medium-grain line RU1901033, and CL long-grain lines RU1801101 and RU2001121 are planned for 2021 for potential releases in 2022. One hundred eighteen breeding lines that outperformed commercial check varieties in AYT, CAYT, CSIT, and SIT trials were selected and further evaluated in the laboratory as candidates for 2021 advanced yield trials, including PC, ARPT, CRT, and URRN.

Practical Applications

Successful development of medium-grain varieties Titan, CLM04, and Lynx, and the long-grain variety CLL15 offers producers options for variety and management systems in Arkansas rice production. Continued utilization of new germplasm through exchange and introduction remains important for Arkansas rice improvement.

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Table 1. Performance of selected Clearfield long-grain experimental lines and check varieties in the Clearfield® Stuttgart Initial Trial (CSIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, 2020.

Variety/Line	Pedigree	Seedling vigor[†]	Days to 50% heading	Plant height	Yield	Milling yields (%)	
						Head rice	Total rice
				(cm)	(bu./ac)		
20CSIT317[b‡]	ROYJ*2/14CSIT203	3.0	84	108	249	53.5	67.4
20CSIT533[c]	RU1401136/CL172	3.0	74	100	234	55.1	66.9
20CSIT423[c]	ROYJ/CL111	4.0	79	97	216	57.7	66.5
20CSIT522[c]	RU1601124/RU1601096	3.0	82	98	210	59.0	69.2
20CSIT190[b]	RU1102034/RU1501024	3.0	89	97	202	55.6	68.0
20CSIT509[c]	RU0902140/RU1302045	3.5	78	106	202	60.5	68.3
20CSIT402[b]	CL151/CL153	3.0	83	105	202	59.4	67.1
20CSIT453[c]	RU1601167/DMND	3.0	80	105	201	57.9	65.5
20CSIT241[b]	RU1102192/CL172	3.0	88	104	199	57.9	65.9
20CSIT051[a]	RU1102028/CL111	3.0	94	104	195	n/a	n/a
20CSIT144[a]	MRMT/RU1501185	3.0	92	98	192	60.9	68.6
CLL15[a]	CLL15	3.0	94	100	152	58.1	64.6
CLL16[a]	CLL16	3.0	96	113	179	55.7	62.5
CLL17[b]	CLL17	4.0	85	102	179	n/a	n/a

[†] A subjective 1–7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[‡] a = planted on 6 April, b = planted on 27 April, and c = planted on 13 May.

Table 2. Performance of selected Clearfield medium-grain experimental lines and check varieties in Clearfield® Stuttgart Initial Trial (CSIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, 2020.

Variety/Line	Pedigree	Seedling vigor[†]	Days to 50% heading	Plant height	Yield	Milling yields (%)	
						Head rice	Total rice
				(cm)	(bu./ac)		
20CSIT486[c‡]	16ARPT271/RU1601050	3.0	80	103	245	64.0	67.6
20CSIT364[b]	RU1301030/14CSIT314	4.0	84	101	237	60.9	66.9
20CSIT502[c]	JPTR/TITN//15CSIT769	3.0	78	105	220	62.5	65.9
20CSIT476[c]	NPTN/15CSIT749	3.0	81	102	219	56.5	63.1
20CSIT469[c]	CFFY/15CSIT749	3.0	81	105	218	60.8	66.3
20CSIT290[b]	RU1501050/RU1501027	3.0	87	102	214	60.2	66.2
20CSIT485[c]	16ARPT271/RU1601050	3.0	81	99	214	59.1	67.2
20CSIT260[b]	NPTN/RU1501096	3.0	90	100	209	59.8	64.2
20CSIT493[c]	16AYT054/15CSIT771	3.0	80	103	207	63.2	66.3
20CSIT470[c]	CFFY/15CSIT749	3.0	81	99	206	54.2	66.5
20CSIT256[b]	CFFY/RU1501027	3.0	84	102	202	60.8	64.7
20CSIT034[a]	JPTR/CL261	3.0	90	100	179	n/a	n/a
CLM04[a]	CLM04	3.0	93	112	172	60.9	64.0
CLM04[b]	CLM04	3.0	86	106	215	n/a	n/a
CLM04[c]	CLM04	3.0	82	103	210	n/a	n/a

[†] A subjective 1–7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[‡] a = planted on 6 April, b = planted on 27 April, and c = planted on 13 May.

Table 3. Performance of selected conventional medium-grain experimental lines and check varieties in Stuttgart Initial Trial (SIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, 2020.

			Days to			Milling yields (%)	
Variety/Line	Pedigree	Seedling vigor[†]	50% heading	Plant height	Yield	Head rice	Total rice
				(cm)	(bu./ac)		
20SIT0580[a‡]	STG09PR-82-038/07SP308	3.0	86	106	240	n/a	n/a
20SIT0589[a]	07SP296/07SP308	3.0	86	98	237	n/a	n/a
20SIT0838[b]	14SIT822/14SIT835	4.0	81	103	232	n/a	n/a
20SIT0796[b]	CFFY/14SIT891	3.5	87	101	232	n/a	n/a
20SIT0829[b]	RU1201124/07SP259	4.0	79	99	230	n/a	n/a
20SIT0827[b]	14SIT818/14SIT873	3.0	82	99	230	61.8	65.3
20SIT0581[a]	RU0502137/07SP291	3.0	85	100	226	56.7	64.9
20SIT0914[b]	RU1301130/TITN	4.0	86	100	211	58.0	66.8
20SIT0845[b]	JPTR/EARL	4.0	86	96	209	63.5	67.5
20SIT0873[b]	16AYT056/16AYT055	4.0	83	102	206	58.5	66.5
20SIT0783[b]	JPTR/14SIT873	3.5	86	96	206	65.8	68.7
20SIT0600[a]	9902028/3/BNGL//MERC/RICO/4/CFFY	3.0	87	106	202	64.2	67.8
Jupiter[a]	Jupiter	3.0	87	95	167	63.8	67.2
Titan[b]	Titan	3.0	80	97	186	n/a	n/a
Lynx[b]	Lynx	3.0	85	106	210	n/a	n/a

[†] A subjective 1–7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[‡] a = planted on 16 April and b = planted on 27 April.

Table 4. Performance of selected conventional long-grain experimental lines and check varieties in Stuttgart Initial Trial (SIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, 2020.

Variety/Line	Pedigree	Seedling vigor[†]	Days to 50% heading	Plant height	Yield	Milling yields (%)	
						Head rice	Total rice
				(cm)	(bu./ac)		
20SIT0949[b‡]	RU1201111/DMND	4.0	84	112	262	62.1	69.6
20SIT0928[b]	FRNS/TGRT	3.5	87	114	258	60.5	70.7
20SIT0931[b]	DMND/TGRT	3.0	86	119	248	59.4	69.2
20SIT0662[a]	DMND/LKST	3.0	87	115	247	61.5	68.4
20SIT0930[b]	FRNS/TGRT	3.0	86	114	243	61.3	70.1
20SIT1091[c]	ROYJ/RU1501127	3.0	82	111	240	61.4	69.4
20SIT0985[c]	RU1701084/RU1601070	3.0	83	108	239	49.7	69.9
20SIT1067[c]	RU1401142/RU1201111	3.0	82	118	239	60.0	68.9
20SIT0934[b]	ROYJ/RU1201136	3.0	90	119	239	62.3	69.7
20SIT0935[b]	FRNS/DMND	4.0	84	111	239	58.2	69.3
20SIT0965[c]	ROYJ//ROYJ/RU0902140	3.0	82	114	238	58.5	69.4
20SIT0929[b]	FRNS/TGRT	3.5	84	111	237	62.7	71.1
Diamond[a]	Diamond	3.0	88	116	192	n/a	n/a
Diamond[b]	Diamond	3.0	86	111	217	58.3	68.6
Diamond[c]	Diamond	3.0	80	106	227	n/a	n/a

[†] A subjective 1-7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[‡] a = planted on 16 April, b = planted on 27 April, and c = planted on 13 May.

Table 5. Average yield, milling, and agronomic characteristics of selected experimental long-grain and medium-grain lines and check varieties tested in the Uniform Regional Rice Nursery (URRN) in Arkansas, Louisiana, Mississippi, Missouri, and Texas, 2020.

Entry	Pedigree	Grain type[†]	Days to 50% heading	Plant height	Yield	Milling yields (%)	
						Head rice	Total rice
				(cm)	(bu./ac)		
RU1801238	EARL/9902028//RU1202068	CM	93	101	202	60.4	70.2
RU1901137	CL271/JPTR	CM	97	97	200	57.1	68.9
RU1901169	EARL/9902028//RU1202068	CM	86	99	211	61.7	70.9
RU1801101	CL172/RU1102034	CL	91	103	191	61.8	69.0
RU1901129	RU1102131/14CSIT203	CL	91	98	196	64.4	71.0
RU2001121	RU1102131/14CSIT203	CL	92	103	196	64.5	71.6
RU2001129	RU1102131/CL172	CL	90	95	194	63.3	71.5
RU2001125	ROYJ/RU1501127	L	91	110	210	60.1	69.5
RU2001185	DMND/LKST	L	90	109	211	58.0	70.0
RU1801237	JPTR/EARL	M	93	93	201	63.6	69.7
RU1901033	RICO/BNGL//RU0602162/RU0502031	M	88	90	183	61.4	68.5
Lynx	Lynx	M	92	103	202	58.5	67.0
Jupiter	Jupiter	M	92	98	195	61.8	67.5
Titan	Titan	M	87	101	202	63.3	68.8
CLL15	CLL15	CL	89	95	182	61.0	69.1
CLL16	CLL16	CL	96	107	214	53.8	67.2
CLM04	CLM04	CM	92	107	179	63.0	68.6
Diamond	Diamond	L	91	105	211	55.9	68.2

[†] CL = Clearfield® long-grain, CM = Clearfield® medium-grain, L = long-grain, and M = medium-grain.

Developing Hybrid Parental Lines and Innovating Techniques for the Hybrid Rice Seed Production

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Abstract

In the past few years, hybrid rice production has increased considerably in Arkansas. There are several private and academic institutions in the United States involved in hybrid rice breeding. In 2020, the University of Arkansas System Division of Agriculture's hybrid rice breeding program focused on two activities of hybrid rice parental line breeding and hybrid rice development. Three male-sterile lines suitable for a two-line system (EGMS lines) were advanced and are currently being tested for seed yield production in the winter nursery. A total of 15 male parents, including 13 restorer lines for three-line and 2 for two-line systems, have been developed. Meanwhile, we continue to improve techniques for the hybrid rice F_1 seed production at large plot size.

Introduction

Production of hybrid rice has reached 67% of the rice-growing region in Arkansas due to its high productivity (Hardke, pers. comm.). Several factors are involved in successful hybrid rice production, including developing superior hybrid parental lines, the ability of mass production of the male-sterile lines, as well as F_1 hybrid seeds, developing hybrid cultivars with good yield and milling quality, tolerance to biotic and abiotic stresses as well as lodging and shattering (Virmani and Sharma, 1993; Mao et al., 1998). Seed yield in hybrid rice is dependent on heterosis resulting from the exploitation of genetic diversity between two parents (Virmani, 1997). Acceptable cooking characteristics require the development of hybrid rice with intermediate amylose content and intermediate gelatinization temperature (Khush and Aquino, 1994).

There are two systems of hybrid rice seed production: 1) three-line hybrid rice system that includes Cytoplasmic male-sterile (CMS), Maintainer (B), and Restorer (R) lines, and 2) two-line hybrid system that requires an Environment sensitive genic male sterile (EGMS) and a normal pollinator. The source of sterility in an EGMS line is a gene influenced by environmental conditions such as temperature, light, or both (Virmani, 1997). North (2019) reported that the EGMS lines in the hybrid line development program are thermo-sensitive male-sterile lines (TGMS) and determined the temperature threshold for each TGMS line.

Seed production of male-sterile lines is one of the challenges in hybrid breeding. The production of hybrid seed is influenced by several factors such as flowering behavior (larger stigma and higher exsertion of panicle and stigma) of male-sterile lines, the ratio between male and female parents in a test cross or seed increase plot, synchronization between male and female plants, application of GA3, and method of cross-pollination (Yuan and Virmani, 1988). Our objectives in 2020 were 1) to develop hybrid parental lines including TGMS, maintainer, restorer, and Provisia lines, 2) to cultivate and evaluate experimental hybrid lines, and 3) to innovate techniques to improve seed yield from the male sterile and F_1 hybrid combinations.

Procedures

Developing Male Sterile Lines

In order to develop male-sterile lines for the two-line hybrid production system, numbers of populations from the early to advanced generations were grown in field and greenhouse conditions and evaluated based on their genetic compositions, such as the presence of genes associated with intermediate amylose content and intermediate gelatinization temperature both related to the cooking quality, semi-dwarf gene associated with the plant height, and blast resistance in their genomes. The recorded phenotypic characteristics includes the percent of sterility, panicle and stigma exsertion, plant height, plant shape, heading date, lodging, shattering, and uniformity. The F_2–F_3 generations were planted in a single 6.0-m space-planted row. The intermediate (F_4–F_5) generations were space-planted in eight 3.0-m row plots. The advanced generations (F_6–F_7) were planted in 2 replications, 8 rows of 3.0-m length. The male-sterile line UAS19 (F_9) was planted in 5 plots of 8 rows and 3.0-m length, and two planting dates to serve as the source of male-sterile plants for the test-cross procedure and pure seed production. The selected plants from early and intermediate generations were ratooned and transferred to a greenhouse under suitable conditions for seed production. Seeds from three advanced lines that were grown in a greenhouse were collected and used for the seed increase in the 2020 winter nursery. For developing the CMS line, several B lines were tested in the field, and seeds from selected plants were harvested and sent to the winter nursery.

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Male Parent Development

Thousands of lines were grown and evaluated to be assigned as pollen donors for hybrid rice production. The selection process was similar to what was described for the male-sterile parents. In addition, more than 350 lines were grown in Puerto Rico and harvested in December 2020. The breeding method applied for the restorer line development is single panicle descent. A total of 15 male parents, including 13 restorer lines for three-line and 2 pollen donors for the two-line hybrid rice production systems, were selected and will be added in the 2021 test-cross field. Further study showed that of all advanced lines,16 lines produced higher seed yield than checks, including Diamond, Lakast, Titan, and Roy J. Of these 16 high yielding lines, 2 lines will be placed in the 2021 ARPT trial. A field screen of all advanced and intermediate pollen donor lines showed that these lines were tolerant to blast, false smut, panicle sheath rot, bacterial panicle blight but showed a different level of tolerance to narrow brown leaf spot under the natural infestation.

Developing Provisia Lines

We continued to develop Provisia Lines. Several F_2 populations derived from crosses between Provisia line BAS-05AT-I1 HPH12-14BIAT05-LOT-B181 and several UA male-sterile lines were grown and evaluated for herbicide tolerance and sterility in summer 2020. A total of 285 F_2 plants were selected, ratooned, and transferred into the greenhouse, and $F_{2:3}$ seeds from each plant were harvested. The $F_{2:3}$ lines will be grown and evaluated in summer of 2021. Meanwhile, 19 new populations resulting from the Provisia line and 19 rice cultivars/advanced lines were initiated. Male parental lines will be developed from these 19 populations for hybrid seed production. The F_1 seeds from these populations were planted in winter 2020 and will be backcrossed with their recurrent parents.

Heterosis Study

A total of 176 experimental hybrid lines were grown at two locations of Stuttgart and Kiser and evaluated for grain yield and milling quality. The selected experimental hybrid line will be seed increased and placed in the 2021 ARPT trial. Meanwhile, two selected experimental hybrid lines that were previously tested in the heterosis study will be placed in the 2021 ARPT trial. Furthermore, we initiated a greenhouse study to evaluate the hybrid seed purity before placing it in the ARPT.

Male Sterile Seed Production

We tested several locations in Arkansas, Florida, and Puerto Rico to find suitable places for male sterile line increase, and so far, Lajas located in Puerto Rico is found to be appropriate for seed increase in winter. North (2019) reported that temperature induces sterility when it rises above the critical threshold at R2 + 10 d of the male-sterile line's plant growth stage. In Puerto Rico, the month of January's daily high temperatures averages 83.8 °F (28.8 °C) and February at 84.0 °F (28.9 °C) according to historical weather data (Weather Atlas, 2021). Therefore, the male-sterile line planted from 1 November to 10 December has a good chance to stay within fertile producing weather.

Hybrid Seed Production

One of the main objectives of the hybrid breeding program is to implement techniques for hybrid seed production that are compatible with industrial-scale mass seed production. We utilized our 4-row Almaco cell planter and tractor GPS by planting with an 8-in. offset to plant 8 rows. This allowed us to alternate female and male parent rows while minimizing row spacing. Closer contact and reduce tillers allowed for maximum crossing possibilities. Since the number of 2020 test-crosses, as well as the plot size, were increased, a MudMaster with modifications was utilized to allow one person to pollinate all the crosses multiple times a day. The MudMaster followed the same paths in the field, which made for deep ruts that lowered the overall height of the machine in which the bottom dragged across the top of the rice.

Panicles of the male-sterile liine do not exsert completely from their flag leaf sheath due to defective gibberellin biosynthesis genes (Virmani, 1997). UAS19 panicle exsertion was improved with two Gibberellic Acid (GA3) applications (4 oz/ac) at 5% heading and 3 days after the first application. A primary evaluation showed that there was an average of 15% increase of panicle exertion when using the 2 applications of GA. Moreover, the plant height of the treated plants was significantly increased compared to the untreated plants.

Results and Discussion

Developing Hybrid Parental Lines

In 2020, we developed three male-sterile lines and 15 pollen male parents, including 13 restorer lines and 2 pollen donors for two-line hybrid production. These lines will be used for the 2021 hybrid line production. Developing hybrid parental lines is an essential part of a successful hybrid breeding program. There are thousands of lines, including male-sterile; restorer and pollen donor; and maintainer lines that were grown in 2020. Our long-term plan for developing hybrid parental lines includes 1) diversifying the germplasm with newly selected genotypes 2) integrating genes/QTLs associated with agronomic traits into the male-sterile parent and 3) identification of heterotic groups within our long grain rice germplasm to develop new pollen donor lines.

Developing Hybrid Lines

In the past few years, several methods, including plot design, application of GA, synchronization between male and female, pollination methods, etc., were tested for increasing hybrid rice production. In order to minimize outcrossing, there was a 6.0-m distance between 2 plots placed in different bays. It is customary to use a plastic sheet or nylon tent to provide a barrier to prevent possible pollen contamination, but this method is costly, time-consuming, and labor-intensive; therefore, the hybrid program planted corn between bays to minimize outcrossing. Hybrid (F_1) seed production is another issue in hybrid breeding production. The transplanting method is labor-intensive and doesn't produce enough seed for the ARPT study. Therefore, the hybrid breeding program designed a testcross field consisting of more than 360 plots. Each plot comprised different pollen donors and selected female lines. An effective period of pollination usually takes about

5 to 7 days. Also maximum seed production requires shaking male plants every 30 min. In general, the cross-pollinating process is done by using bamboo sticks or rope by shaking a male parent on a female parent, but the method is labor-intensive. In 2019 a blower was used for this matter, but it was not effective since it spread pollens in the air instead of on a female parent. In 2020 a Mudmaster was used. This method successfully pollinated female parents; however, the method was very time-consuming since the pollen stuck to the chain and the Mudmaster; thus, it was necessary to clean up the chain with alcohol between crosses. In 2021, we are planning to use a rope across the whole bay.

Another goal in the hybrid breeding program was to determine the optimum ratio between male and female parents for maximum seed production in the testcross and F_1 seed increase fields. The ratio varies by different locations and countries. The optimum ratio for F_1 seed production determines how to maximize the number of female rows and reduce the number of male parents while pollen still is available for female parents. The hybrid breeding program is initiating a plan to identity such a ratio suitable for Arkansas hybrid rice production.

Application of GA hormone considerably increased panicle exsertion but did not affect flowering date and stigma exsertion. The hybrid breeding program is planning to determine the optimum amount of GA application since such information for Arkansas is not available.

It was observed that the male sterile line flower differently than normal rice genotypes. Rice breeders mainly take data from 10 and 50 percent heading date. The flowering date must be recorded from both male and female parents. We observed that the male-sterile plant's panicles tend to flower about 5 to 7 days after heading. In some cultivars/advanced lines flowering occurred one to one and half days after panicle exsertion, while in other genotypes the stigma exserts from the floret as soon as panicle exsert from its flag leaf. A flowering date should be recorded, while heading dates may not be very accurate for determining the flowering synchronization of hybrid parents.

The results showed that the experimental hybrid lines developed by the hybrid breeding program are generally taller than other hybrid lines, but they show good tolerance to lodging. For example, the experimental hybrid lines did not lodge after 2020 storm while many inbred and hybrid rice cultivars lodged.

Practical Applications

In 2020 we developed several hybrid parental lines, including 3 male-sterile lines and 15 male parents. Meanwhile developing Provisia line and maintainer line were continued. Four lines, including two experimental hybrid lines and two inbred (pollen donor), were selected and will be placed in 2021 ARPT. Several techniques were implemented for hybrid rice production, and new techniques will be used in 2021.

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Development of Aromatic Rice Varieties

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Abstract

Consumers in the United States are exploring new food products and enjoying the farm-to-table experience. Interest in aromatic rice has increased with the advent of nouveau cuisine and the 'identity preservation' ideals of the farm-to-table movement. Sales of aromatic rice have led long-grain rice imports to increase over 58% in the last nine years. The University of Arkansas System Division of Agriculture's Aromatic Rice Breeding Program at the Rice Research and Extension Center (RREC), Stuttgart, Arkansas, was implemented to develop aromatic rice varieties for the southern rice-producing regions. Evaluating cultural practices is essential for selecting advanced lines in the breeding program as well as for growers. Information regarding successful cultural practices for aromatic rice varieties is limited in the southern United States growing regions, and especially for Arkansas.

Introduction

Aromatic varieties imported from Thailand, India, Pakistan, and Vietnam are expected to make up the majority of the expected 29.5 million cwt long-grain imports to the United States in 2020/2021 (USDA-ERS, 2020). Approximately 117,000 tons of rice were imported to the United States from Thailand, the largest supplier of imports, and more than 70,000 tons of rice were imported from India through October 2020 (USDA-ERS, December 2020). Over the past 11 years (Market Years 2009/2010 to 2019/2020), rice imports from India and Thailand have increased 138% and 70%, respectively, with most of the imported rice being premium aromatic (USDA-ERS, 2017 and USDA-ERS, 2020). United States consumers are purchasing more aromatic and/or specialty rice. Producers in the United States find it difficult to grow the true jasmine and basmati varieties due to environmental differences, photoperiod sensitivity, fertilizer sensitivity, and low yields. Adapted aromatic rice varieties need to be developed for Arkansas producers that meet the taste requirements for either jasmine or basmati.

Procedures

The University of Arkansas System Division of Agriculture's Aromatic Rice Breeding Program at the Rice Research and Extension Center (RREC), Stuttgart, Arkansas, has collected parental material from the U.S. breeding programs and the USDA World Collection. Crosses have been made to incorporate traits for aroma, yield, improved plant type, superior quality, and broad-spectrum disease resistance. The winter nursery at the University of Puerto Rico, Lajas Agricultural Experiment Station is being employed to accelerate generation advance of potential varieties for testing in Arkansas during the summer of 2021.

Results and Discussion

In 2020, selections were made from approximately 689 lines in 37 populations grown in the F_4, F_5, F_6, and F_7 nurseries. The parents in these crosses were selected for their aromatic seed quality or high yield potential. Samples from heterozygous lines collected from the F_5, F_6, F_7, and F_8 populations have been submitted to undergo molecular marker analysis. Lines that have the preferred markers for aroma, cooking quality, and blast resistance will be entered in yield trials in 2021.

In a two-replication preliminary trial planted in 2020, 40 aromatic lines were evaluated for yield. In the Aromatic Stuttgart Initial Test (ASIT), which has three replications, 40 aromatic lines were evaluated for yield and potential release. In the four-replication Aromatic Advanced Yield Trial (AAYT), 30 aromatic experimental lines were evaluated for yield and potential release. Four experimental lines were selected to be entered in the Arkansas Rice Performance Trials (ARPT) in 2021. Five aromatic experimental lines have also been entered in the 2021 Cooperative Uniform Regional Rice Nursery (URRN).

In 2020, five jasmine-type experimental lines were entered in the URRN. The Arkansas mean yields for ARoma 17 and the five lines were as follows: ARoma 17, 167 bu./ac; EXP19189, 145 bu./ac; EXP19206, 175 bu./ac; EXP19231, 156 bu./ac; EXP20105, 169 bu./ac; and EXP20109, 138 bu./ac. The URRN Arkansas two-year average yields were: ARoma 17, 175 bu./ac; EXP19206, 183 bu./ac; and EXP19231, 153 bu./ac. The URRN Arkansas three-year average yield for ARoma 17 is 174 bu./ac.

The four experimental lines were also entered in the 2020 ARPT. The mean yields for ARoma 17 and the four lines were as follows: ARoma 17, 167 bu./ac; EXP19189, 164 bu./ac; EXP19206, 180 bu./ac; EXP19231, 167 bu./ac; and EXP20105, 154 bu./ac. The ARPT two-year average yields were: ARoma

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17, 173 bu./ac and EXP19206, 180 bu./ac. The ARPT three-year average yield for ARoma 17 is 170 bu./ac.

One experimental line being considered for release is EXP19231, which has a pedigree including Jazzman, a short-season experimental line from the University of Arkansas System Division of Agriculture, and Taggart. EXP19231 has excellent flavor and will continue to be examined in the ARPT and URRN in 2021. Breeders' Seed will be planted, USDA descriptor data will be collected, and yield data will be collected in 2021 for the possible release of EXP19231 in the near future.

Practical Applications

The project develops new aromatic lines with improved performance for the Arkansas and mid-South producers to meet U.S. consumers' growing demand for locally grown aromatic rice to feed their families.

Acknowledgments

The authors appreciate the financial support of the rice producers of Arkansas through monies administered by the Arkansas Rice Research and Promotion Board. Support is also provided by the University of Arkansas System Division of Agriculture.

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Rice Breeding and Pathology Technical Support

S.B. Belmar,[1] C.D. Kelsey,[1] K.A.K. Moldenhauer,[1] and Y. Wamishe[1]

Abstract

The development of disease-resistant rice is one of many goals rice breeders work on at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas. The center's plant pathology group assists by screening preliminary to advanced breeding entries for disease reaction under greenhouse and field conditions. Breeding materials are evaluated in the field for sheath blight and greenhouse for leaf blast using artificial inoculum. Both sheath blight and blast inocula are produced in the laboratory and applied to rice plants using a specific protocol for each disease. The major objectives of this technical support are to provide data that not only help rice breeders remove the most susceptible lines early in their program but also to support the advancement of lines or transfer of genes for resistance into adapted and high-yielding varieties. The breeding and pathology technical support group assists the extension rice pathology programs with applied research to manage diseases that prevail in rice fields, as well as collaborative interdepartmental, industry, and multi-state research endeavors.

Introduction

Rice breeders and pathologists work together to develop varieties having desirable disease resistance along with desired agronomic traits. Disease evaluation of rice against the major rice diseases begins in the early generations of plant selection and is a required activity for a successful breeding program. Rice lines having some potential traits that do not meet the desired levels for release may become parents to develop other new varieties.

Rice blast, caused by *Magnaportha grisea* (T.T. Herbert) M.E. Barr, is still an important disease. Due to budget cuts and the Covid-19 pandemic, breeding materials are evaluated for leaf blast using rice seedlings from the greenhouse only rather than to also establish a field blast nursery with fully mature plants. Screening plants for blast requires desired environmental conditions prior to and after inoculation for the pathogen to cause disease.

Sheath blight, caused by (*Rhizoctonia solani* Kuhn), is another problematic fungal disease of rice. Germplasm are evaluated on fully-grown plants in the field at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas. While no qualitative resistance to this pathogen exists, knowledge of whether a variety can tolerate infection through reduced spread of the pathogen is valuable to breeding programs. Inoculum production to enhance sheath blight disease in plots requires a large amount of a corn/rough rice seed mixture as a carrier of sclerotia and mycelia of the fungus used to start the disease.

Procedures

Greenhouse Evaluation of Breeding Materials for Blast Resistance

Entries of the Arkansas Rice Performance Trials (ARPT), Aromatics, Imidazolinone ARPT (IMI-ARPT), Imidazolinone Stuttgart Initial Test (IMI-SIT), and Uniform Regional Rice Nursery (URRN) were evaluated as hill plots for their resistance to leaf blast. Tests were replicated to generate 3 disease observations per entry. Approximately 170 flats of soil were prepared to produce 3 to 4 leaf seedlings. Each replicate was spray inoculated using individual spore suspensions made of *M. grisea* races: IB1, IB49, IC17, IB17, and IE1K. Inoculum production and disease establishment followed earlier described procedures (Kelsey et al., 2016). Disease data were collected 7 to 10 days after inoculation using two rating scales. Disease severity rating used the 0 to 9 scale where zero (healthy leaves) and nine (elongated necrotic lesions on leaves). The incidence scale estimated relative lesion coverage on the leaf blades, i.e., one (single leaf or lesion) to 100 (all leaves necrotic with multiple lesions). Testing of entries in the Preliminary Test (Prelims) and Aromatic Prelims used a bulk spore suspension that was prepared by combining the 4 races of IB1, IB49, IC17, and IB17. Entries were tested separately with IE1K due partially to the aggressiveness of this race to most rice with or without *Pi-ta* genes.

Field Evaluation of Breeding Materials for Sheath Blight

For sheath blight tolerance, a nursery at the RREC was planted on 1 May in two adjacent bays. Five reps of entries for ARPT, Aromatics, IMI-ARPT, SIT, IMI-SIT, Prelims, and URRN were planted for a total of 1,128 -hill plots per rep. On 10 July, plants (at panicle initiation stage) were hand inoculated with a mixture of two relatively slow-growing *R. solani* isolates (approximately 20 gallons), at the rate of 24g (1 oz) per six hill plot row. In addition, a subset of 52 entries from the 2019 URRN test, which represented tolerant or susceptible disease reactions with the slower growing fungal isolates, was planted in 10 rep sets. Half of the sets were hand inoculated with "slow-growing" *R. solani,* while the other half received the "faster-growing" fungal isolates. About five weeks later, a fungal disease assessment of each hill plot was carried out using a rating scale of zero (no disease) to nine (severe disease that reached the flag leaf).

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Assistance to Extension Rice Pathology

The breeding pathology technical support assisted with the planting of 6 field experiments designed to collect data for control of sheath blight and early season seedling disease. All tests screened products for control of sheath blight or for seedling diseases. These tests utilized artificial inoculation with *R. solani,* and fungicides were applied to 168 rice plots. Twenty-nine products were tested for control of sheath blight. For seed treatment studies on seedlings, data were collected on stand count and seedling height. A fungicide spray coverage study on sheath blight and false smut consisted of 40 plots to evaluate 3 and 10 gallons per acre (GPA) spray volumes of fungicides for management of these diseases. In breeder's fields, over 1,200 plots that contained preliminary and advanced breeding lines were assessed for major rice diseases that occurred naturally in the field.

Results and Discussion

Disease assessment of rice for resistance/tolerance to sheath blight and blast was completed for the breeding program. For each of the tests, several tolerant entries to sheath blight were identified (Table 1). The use of slower colonizing isolates of *R. solani* continued to meet the objectives for sheath blight screening since more than 50% of the entries were classified as susceptible. Based on the subset of 52 entries from the 2019 URRN test, 67% of the entries consistently scored as tolerant or susceptible for 2 years in a row using the "slow" growing fungal isolates. With "fast" growing isolates, agreement on the susceptibility of entries for 2 years was greatly reduced to around 20%. By combining the results of both inoculum types, 8 entries were consistently identified to be classified as tolerant to sheath blight, thus making them potentially useful to the breeding program as potential sources of disease tolerance.

Of the 975 experimental lines tested for leaf blast in the greenhouse with individual races of blast, several were rated as disease tolerant (Table 2). Collection of incidence data along with severity data was helpful toward distinguishing test entries that have the potential for advancement from those identified as possible mechanical seed mixture or due to segregation.

The breeding–pathology technical support has significantly contributed towards the success of research activities in breeding and extension rice pathology programs. The assistance covers studies in laboratory, greenhouse, and field, as well as collaborative research with industries and interdepartmental research.

Practical Applications

The rice breeding-pathology technical support group provides disease data to the breeding program to minimize the most susceptible materials from advancing and allows selection and development of new high-yielding cultivars with anticipated levels of disease resistance. In addition, technical support is core in extension plant pathology with involvement in applied research. Data generated by the extension pathology program provides dependable and practical information for rice producers in Arkansas and other rice-producing states. The technical support group is actively working with breeders and the extension rice pathology program to improve rice productivity for the Arkansas grower.

Acknowledgments

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Table 1. The number of entries rated sheath blight tolerant in 2020 field nursery.

Test	Total entries screened	Entries tolerant using “slower” growing isolate[a]
ARPT[b]	46	16
URRN	239	66
Aromatics[c]	119	43
SIT	125	51
IMI-ARPT	88	28
IMI-SIT	187	77
Prelims	171	82

[a] Rating scale of 0 (no disease) to 9 (severe disease) was used. A “6” represents disease progression of approximately 60% up the plant and considered tolerant for average scores of 6.3 or less.

[b] ARPT = Arkansas Rice Performance Rice Trials; URRN = Uniform Regional Rice Nursery; SIT = Stuttgart Initial Test; IMI = Imidazolinone.

[c] Collectively includes Arkansas Yield Trials, Stuttgart Initial Trials and Preliminary varieties.

Table 2. The number of entries rated disease tolerant[a] for 2020 greenhouse leaf blast testing.

Test	Total Entries	IE1K	IC17	IB17	IB49	IB1
ARPT[b]	46	15	17	24	11	17
URRN	239	74	118	66	88	67
Aromatics[c]	77	29	43	17	34	22
SIT	125	50	32	40	36	38
IMI-ARPT	88	18	33	23	19	22
IMI-SIT	187	70	80	61	51	50
			Bulked across the individual races			
Aromatic Prelims	42	26	13			
Prelims	171	62	47			

[a] Disease severity rating scale of zero (no disease) to four (small diamond-shaped lesion with ashy center).

[b] ARPT = Arkansas Rice Performance Rice Trials; URRN = Uniform Regional Rice Nursery; SIT = Stuttgart Initial Test; IMI = Imidazolinone.

[c] Collectively includes Arkansas Yield Trials and Stuttgart Initial Trials varieties.

Investigating the Genetic Basis of Resistance to Bacterial Panicle Blight of Rice Under Heat Stress Conditions

L. Ortega[1] *and C.M. Rojas*[1]

Abstract

The disease bacterial panicle blight (BPB), caused by the bacterium *Burkholderia glumae,* has affected rice production in Arkansas. It directly affects yield as *B. glumae* infects reproductive tissues interfering with grain development. Bacterial panicle blight has been more prevalent in years with unusually high temperatures, especially at night, suggesting that this disease will have devastating consequences with the continuous rise in global temperatures. The development of rice cultivars resistant to BPB under conditions of heat stress necessitates the identification of sources of resistance, as well as detailed analysis of genes and regulatory networks underlying such resistance. A previous screen to characterize rice responses to BPB under conditions of heat stress demonstrated that rice accessions' responses to the combination of *B. glumae* and heat are varied. This work uses accessions with contrasting responses to evaluate their gene expression profiles to gain more information on the genetic basis of resistance to BPB under heat stress.

Introduction

The disease bacterial panicle blight (BPB) caused by *Burkholderia glumae* has affected rice production in Arkansas. Severe cases of BPB can cause a reduction in grain weight of up to 75% that can translate into significant yield losses (Fory et al., 2014).

Bacterial panicle blight outbreaks in the Mid-South region of the U.S. had occurred in years when temperatures have been unusually high, especially at night (Wamishe et al., 2015; Shew et al., 2019), suggesting that the interaction between *B. glumae* and heat can exacerbate BPB. We previously screened 20 rice accessions from the USDA mini-core collection for resistance against *B. glumae* under normal and heat stress conditions and found a range of responses in those accessions (Ortega et al., 2019). The responses of some accessions were independent of temperature, and such accessions were either moderately resistant or susceptible at both normal temperature and high temperature. Other accessions were moderately resistant at normal temperatures but susceptible at high temperatures, while others were susceptible at normal temperatures but moderately resistant at high temperatures (Ortega et al., 2019). These results demonstrate that the interaction between BPB and heat has a strong genetic component that needs to be dissected further. This work selected two accessions exhibiting contrasting responses to *B. glumae* under normal temperatures and high temperatures to evaluate the expression of target genes. The results revealed the relationships between contrasting phenotypic responses and differential gene expression.

Procedures

Plant Material

Two accessions were previously identified as having contrasting responses after inoculation with *B. glumae* and two distinct temperature regimes: normal temperature [86 °F (30 °C) day, 72 °F (22 °C) night] and high temperature [86 °F (30 °C) day/82 °F (28 °C) night]. Accession GSOR310131 was moderately resistant at normal and high-temperature conditions, while accession GSOR311383 was susceptible to *B. glumae* at both temperatures.

RNA Extraction and cDNA Synthesis

Flag leaves from *B. glumae*- or water-treated plants were harvested in liquid nitrogen 3 days after treatment. Three replications per experimental condition were harvested. Flag leaves were ground using 1600 MiniG® automated tissue homogenizer (Spex Sample Prep, Metuchen N.J.), and total RNA was extracted using Trizol reagent (Life Technologies, Carlsbad, Calif.). RNA was precipitated with 5M KOAC pH 5.2, and 100% ice-cold ethanol and air-dried. RNA pellets were resuspended in 20 µl of RNAse-free water. One microgram of total RNA was used for DNAse treatment (TurboDNAse, Thermo Fisher, Waltham, Mass.) followed by cDNA synthesis (High Capacity cDNA Reverse Transcription Kit, Thermo Fisher Scientific, Waltham, Mass.).

Quantitative RT-PCR

Candidate genes were selected from published literature evaluating rice responses to abiotic and biotic stress conditions (Narsai et al., 2013). Gene sequences were obtained from the Gramene database (Ware et al., 2002), and primers were designed to amplify approximately 150 bp from the 3'-UTR region using the Primer Select tool (DNASTAR Lasergene, Madison, Wis.).

For each sample/treatment combination, three biological replicates were utilized. Amplification of cDNA was performed in 20-µl reactions containing 5 µl of cDNA (5ng/µl), forward and reverse primers at 5-µM final concentration and GoTaq qPCR Master Mix (Promega, Madison, Wis.). Two technical replicates per sample were included, and samples were run in a CFX96 Real-Time System (BioRad, Hercules, Calif.) with the following thermal cycling protocol: 203 °F (95 °C) for 10 min, followed by 115 °F (45 °C) for 15 s, and 140 °F (60 °C) for 1 min or a total of 40 cycles.

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Gene expression was calculated using the $2^{-\Delta\Delta Ct}$ method (Livak and Schmittgen, 2001) to compare the expression of a gene of interest between pathogen-inoculated and mock-treated samples and normalized to the expression of Glyceraldehyde-3- Phosphate Dehydrogenase (GAPDH) gene, used as the housekeeping gene.

Results and Discussion

Previous work investigating the interactions between biotic and abiotic stress in rice identified several genes that were induced in responses to several biotic and abiotic stresses, two of those genes were: *Os05g28740*, which encodes a universal stress response protein and *Os06g07030*, which encodes an *AP2*-type transcription factor (Narsai et al., 2013). We decided to evaluate the expression of those genes in the moderately resistant accession GSOR310131 and the susceptible accession GSOR311383 after inoculation with *B. glumae* and under normal and high temperatures. In addition, work in our lab identifying plant defense genes in the model plant *Arabidopsis thaliana*, previously uncovered *AtNHR2B* (*Arabidopsis thaliana nonhost resistance* 2B), as a gene participating in abiotic and biotic stress responses (Singh et al.,2018). We included the *AtNHR2B* rice ortholog, *Os07g159500*, in these experiments.

Quantitative RT-PCR evaluating the expression of these three genes in GSOR310131 and GSOR311383 revealed that in each accession, these genes had higher levels of expression at high temperatures in comparison with normal temperatures (Fig. 1). *Os06g07030* was not differentially expressed between accessions. *Os05g28740* showed significantly higher levels of expression in the moderately resistant accession (GSOR 310131) at both temperatures, and those levels were dramatically increased by 5-fold at higher temperatures. A contrasting pattern was observed with *Os07159500*, wherein the susceptible accession (GSOR31138) showed higher levels of expression at both temperatures, but the highest difference of 2-fold was observed after heat treatment. These results indicate that *Os05g28740* might be involved in activation of defense responses against *B. glumae* in conditions of heat stress, while *Os07g159500* might be involved in repression of those responses.

Practical Applications

Results from this work identified genes that are differentially expressed between a BPB moderately resistant and susceptible accession and those responses vary with temperatures. Future work evaluating additional genes and accessions will identify essential genes that can be incorporated in cultivated varieties to improve resistance to BPB under heat stress.

Acknowledgments

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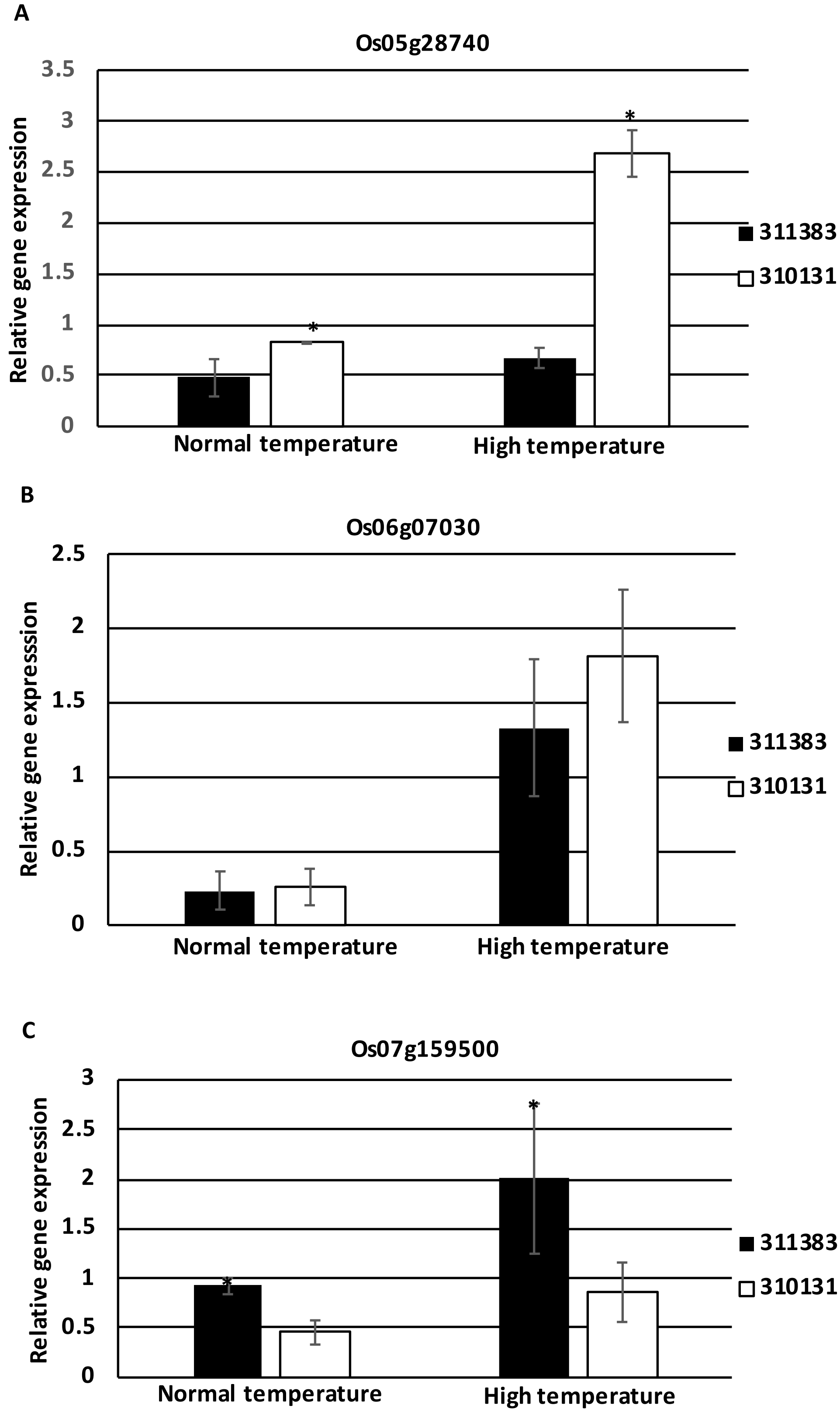

Fig. 1. Differential gene expression between bacterial panicle blight (BPB)-moderately resistant and BPB-susceptible accessions under normal and high-temperature conditions. Quantitative RT-PCR was used to evaluate the expression of *Os05g28740* (A), *Os06g07030* (B), and *Os07g159500* (C), in the moderately resistant accession GSOR310131 and the susceptible accession GSOR311383. Gene expression in *B. glumae*- inoculated samples was normalized to that of mock-treated samples for the same temperature treatment and using Glyceraldehyde-3-Phosphate Dehydrogenase (GAPDH) as the housekeeping gene for normalization.

Control of Rice Diseases in Arkansas by Using Antagonistic Bacteria and Products Derived from Them

L. Ortega,[1] L. Delgado,[2] A. Rojas,[1] and C.M. Rojas[1]

Abstract

Rice diseases such as sheath blight, rice blast, and bacterial panicle blight significantly affect rice production in Arkansas and in other rice-growing areas of the world. Controlling these diseases relies on planting resistant cultivars and, in the case of fungal diseases, chemical control. Neither one of those strategies are durable, as new pathogen variants emerge over time. In the case of bacterial panicle blight, strategies to control the disease are still not available. Therefore, an alternative approach that is durable and environmentally friendly is to use biological control, which takes advantage of living microorganisms, or products derived from them, to interfere with the activities of pathogens. Previously, we identified two bacterial strains: *Pseudomonas protegens* PBL3 and *Burkholderia cepacia* PBL18, with antagonistic activity against *Burkholderia glumae*, the bacterium that causes bacterial panicle blight. We further showed that *P. protegens* PBL3 and *B. cepacia* PBL18, when co-inoculated with *B. glumae*, reduced disease symptoms in rice. Additional characterization revealed that the antagonistic activity of *P. protegens* PBL3 and *B. cepacia* PBL18 was found in the secreted fractions from these bacteria, suggesting that those fractions could be further used as biopesticides. In this work, we further evaluated the use of *P. protegens* and *B. cepacia* to control BPB, sheath blight, and rice blast.

Introduction

The disease sheath blight caused by the fungus *Rhizoctonia solani* AG1-1A is considered the most important disease of rice in the Southern United States as it causes damages every year (Wamishe et al., 2013). Other diseases such as rice blast caused by the fungus *Magnaporthe oryzae* and bacterial panicle blight caused by the bacteria *Burkholderia glumae* are highly dependent on environmental conditions (Wamishe et al., 2013). In particular, Bacterial Panicle Blight (BPB) has significantly affected rice production in the U.S. Mid-South in years when temperatures have been unusually high, especially at night (Wamishe et al., 2015; Shew et al., 2019). BPB directly affects yield as the bacterium interferes with grain development causing reduced grain weight or no grain filling in spikelets (Nandakumar et al., 2009; Fory et al., 2014; Wamishe et al., 2015).

Bacterial panicle blight is challenging to control as effective chemical controls are not available, and completely resistant cultivars have not been developed. Previous work on biological control at the University of Arkansas System Division of Agriculture isolated bacterial strains from wheat fields of Arkansas and investigated their activities against the oomycete pathogen *Pythium* sp (Milus and Rothrock, 1997). We recently tested those strains for antagonistic activity against *B. glumae* and found that two bacterial strains *Pseudomonas protegens* PBL3 and *Burkholderia cepacia* PBL18 inhibited the growth of *B. glumae* growing on Petri plates. These results suggested that *P. protegens* PBL3 and *B. cepacia* PBL18 release (secrete) inhibitory compounds to the media, and additional experiments with *P. protegens* PBL3, demonstrated that indeed that was the case; secreted fractions of *P. protegens* PBL3 without any bacterial cells retained the growth inhibitory activity against *B. glumae*. We further showed that living *P. protegens* PBL3 and *B. cepacia* PBL18, when co-inoculated with *B. glumae*, reduced disease symptoms in rice (Ortega et al., 2020). This work showed that the secreted fractions of *P. protegens* PBL3, lacking living bacteria, was also effective in reducing the effects of *B. glumae* on rice.

In addition to the potential application of *P. protegens* PBL3 and *B. cepacia* PBL18 to control BPB, this work also shows preliminary evidence that *B. cepacia* PBL18 can be effective in controlling fungal diseases in rice.

Procedures

Preparation of Secreted Fractions from *P. protegens* PBL3

P. protegens PBL3 was streaked on Luria Bertani (LB) plates and grow at 82 °F (28 °C) for 18 h. A single colony was transferred to 250 mL of Luria Bertani (LB) broth and grown with aeration at 82 °F (28 °C) for 24 h. Bacterial culture was centrifuged for 10 min at 6,000 rpm, and the supernatant containing bacterial secretions was collected and lyophilized for 24 h. Sterile Luria Bertani broth was also lyophilized using the same conditions and used for control in the experiments. Lyophilized LB and secreted fractions from *P. protegens* PBL3 were resuspended in sterile water at 0.5g/mL and filter-sterilized using a 0.22 µM filter to remove possible contamination or residual bacteria.

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Evaluation of the Effect of the *P. protegens* PBL3 Secreted Fraction on the Pathogenicity of *B. glumae*

To evaluate the effect of cell-free reconstituted secreted fraction from *P. protegens* PBL3 on *B. glumae* infection on seeds, seeds from cultivar Nipponbare were surface-sterilized and incubated with *B. glumae* mixed with resuspended LB, or with *B. glumae* containing cell-free lyophilized fractions of *P. protegens* PBL3 (0.01g/ml) for 10 min. In both preparations, the final bacteria concentration was at OD600 = 0.001. Inoculated seeds were plated on Murashige and Skoog (MS) media and incubated at 77 °F (25 °C) for 5 days in a growth chamber set up at 77 °F (25 °C) and photoperiod of 16 h light/8 h dark.

Biological Control Assays Against Fungal Pathogens

Rhizoctonia solani AG-11, *R. solani* AG-4, *Pythium sylvaticum*, *Pythium ultimum*, *Pythium irregulare*, *Magnaporthe grisea,* and *Fusarium* were isolated from fields in Arkansas and identified in the lab. In order to test the activity of *P. protegens* and *B. cepacia* against those pathogens, two agar plugs containing fungal mycelia were placed on the surface of Malt Extract agar. *P. protegens* and *B. cepacia* were streaked as a line in the middle of the plate. Plates were incubated at 80 °F (27 °C), and fungal growth was measured after 48 hours. The percentage of fungal growth was calculated by measuring the radius of fungal growth in the presence of *P. protegens* or *B. cepacia* versus the respective fungal growth without the bacteria. Three independent experiments were conducted.

Results and Discussion

The *P. protegens* PBL3 Secreted Fraction Reduces Seed Rotting Caused by *B. glumae*

We previously found that secreted fraction of the *P. protegens* PBL3 reduced disease symptoms caused by *B. glumae* in sheath and panicles (Ortega et al., 2020). Since BPB is a seed-borne disease, we further investigated if the cell-free secreted fraction of *P. protegens* PBL3 could be used as a seed treatment. For that purpose, we mixed the cell-free lyophilized fraction of *P. protegens* with the *B. glumae* inoculum and used this mixed inoculum to inoculate rice seeds, using as control *B. glumae* mixed with lyophilized LB. At 5 dpi, *B. glumae* mixed with lyophilized LB caused a reduction in seed germination, and those seeds that germinated had short roots and shoots. In contrast, seeds that were inoculated with *B. glumae* mixed with the secreted fraction of *P. protegens* PBL3 improved seed germination and germinating seedlings had longer roots and shoots in comparison with controls (Fig. 1). These results suggest that secreted fractions from *P. protegens* could be effective seed treatments against BPB.

B. cepacia is Very Effective at Reducing Growth of Fungal and Oomycete Pathogens

We also evaluated the effect of *P. protegens* and *B. cepacia* on fungal and oomycete pathogens by co-cultivation experiments. We found that *P. protegens* significantly reduced the growth of *M. grisea* JC-49, but its effect on other pathogens was minor. However, *B. cepacia* significantly reduced the growth of *R.solani* AG11, *P. sylvaticum*, *P. ultimum*, *P. irregulare*, *M. grisea* G-11, *M. grisea* JC-49 and F. *graminearum* and that effect ranged from 40–60% reduction (Fig. 2). Those results suggest that *B. cepacia* or products derived from it could be harnessed as biological control agents or biopesticides to control fungal and oomycete diseases of crops.

Practical Applications

This work will pave the way towards deploying *P. protegens* and *B. cepacia* as sources to control bacterial panicle blight of rice and other important rice diseases caused by fungal and oomycete pathogens. Controlling these diseases will reduce their economic impact while providing environmentally friendly options that are also accepted by consumers.

Acknowledgments

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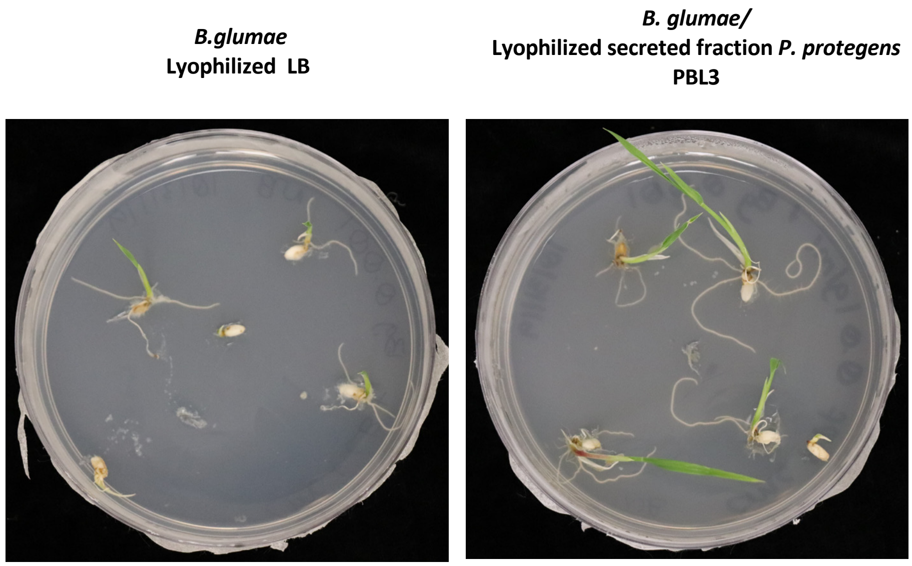

Fig. 1. Secreted supernatants of P. protegens PBL3 protect seeds from *Burkholderia glumae* infections. Cell-free lyophilized LB or secreted cell-free fraction of *P. protegens* PBL3 were reconstituted in sterile water at a final concentration of 0.01g/ml, filter sterilized, and mixed in equal volume with *B. glumae* at OD_{600} = 0.001. Surface-sterilized seeds from cultivar Nipponbare were inoculated with *B. glumae* mixed with lyophilized LB or lyophilized cell-free secreted fraction from *P. protegens* PBL3. Seeds were transferred to Murashige and Skoog (MS) media. Seed germination was evaluated after 5 days post-inoculation.

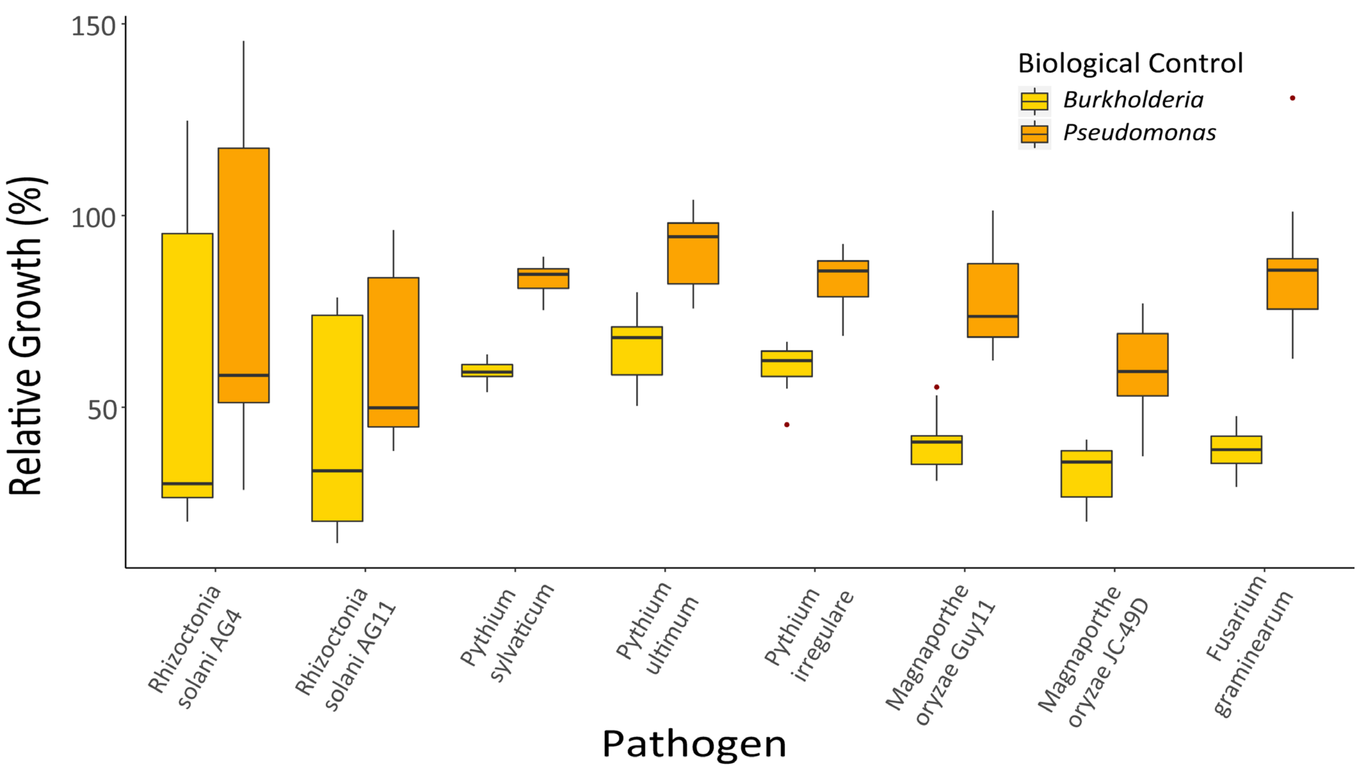

Fig. 1. *B. cepacia* and *P. protegens* interfere with the growth of fungal and oomycete pathogens. *Rhizoctonia solani* AG-11, *R. solani* AG-4, *Pythium sylvaticum*, *Pythium ultimum*, *Pythium irregulare*, *Magnaporthe grisea* and *Fusarium graminearum* were grown on agar plates, and two agar plugs containing mycelia were placed on the surface of Malt Extract agar. *P. protegens* and *B. cepacia* were streaked as a line in the middle of the plate. Plates were incubated at 80 °F (27 °C), and fungal growth was measured after 48 h. The percentage of fungal growth was calculated by measuring the radius of fungal growth in the presence of *P. protegens* or *B. cepacia* versus the respective fungal growth without the bacteria. Three independent experiments were conducted.

Fungicide Application and Coverage for Sheath Blight and False Smut

Y. Wamishe,[1] J. Hardke,[2] T. Gebremariam,[1] S.B. Belmar,[1] C.D. Kelsey,[1] and T.R. Butts[3]

Abstract

Sheath blight caused by *Rhizoctonia solani* AG1-1A is the most prevalent disease in rice fields of Arkansas, causing up to 15% grain yield loss. Nearly 57% of rice fields in Arkansas receive at least one fungicide application every year, and most of these fungicides are to manage sheath blight. In some commercial rice fields, low carrier water volumes used to deliver fungicides are blamed for the lower efficacy of fungicides to suppress diseases such as sheath blight and false smut. Field tests were conducted for the second season in 2020 to evaluate two volumes of water (3 and 10 gallons per acre, GPA) as a carrier for two fungicides applied (Amistar Top and Quilt Xcel at 15 and 21 fl oz/ac rate, respectively. The sheath blight data analysis from the field test of 2020 showed a significant difference between the sprayed and unsprayed plots. However, there was no significant difference in efficacy between Amistar Top and Quilt Xcel in the degree of sheath blight suppression. Sheath blight in unsprayed plots showed progression throughout the season, followed by the plots sprayed with 3 GPA of both fungicides. The highest suppression of the disease was in plots that received fungicides sprayed using 10 GPA. In false smut plots, there were no significant differences between the sprayed and unsprayed plots in the number of galls counted in panicles collected from an 8-ft^2 area inside a plot. Differences between the fungicides and the water amounts used to deliver them were not significant either. Although not significant, the unsprayed check had a lower gall count than the sprayed check, which may be due to the late planting and the greening effect of the fungicides. The size and velocity of droplets were compared between the 3 and 10 GPA carrier volumes for the respective fungicides. The 3 GPA treatments had a greater droplet size and spray classification with an approximate 0.5 mph lower droplet velocity than the 10 GPA treatments. Both aspects may contribute to lower sheath blight suppression over the rice canopy, as shown in this test due to reduced canopy penetration and coverage.

Introduction

Sheath blight in rice is caused by *Rhizoctonia solani* AG1-1A, a soilborne fungus. Sheath blight is a major disease of rice, accounting for up to 15% grain yield loss in Arkansas. The pathogen has a wide host range, including soybean, sorghum, corn, sugarcane, turfgrass, and weed hosts such as barnyard grass, crabgrass, and broadleaf signal grass, among others. As a result, it can be found in any field. The fungus survives in soil as mycelia but mostly as mycelial mass called "sclerotia." The monocyclic infection in flooded rice starts at the waterline. Once infection starts, the disease progresses upward following the height of the crop. Through polycyclic infection, under conditions that favor the fungus' survival and reproduction, it can spread laterally to neighboring plants, mostly by leaf-to-leaf contact. Nearly 57% of rice fields in Arkansas receive at least one fungicide application every year, and most of the fungicides sprayed are to manage sheath blight in susceptible or moderately susceptible rice varieties.

False smut, which is also called orange smut, is relatively a new rice disease in Arkansas. The disease can be minor or very conspicuous depending on the season and favorable conditions. Although the impact of false smut on yield is much lower than sheath blight, in severe situations, it causes chalkiness of grains, which leads to reduction of grain weight. Moreover, seed germination can be reduced. False smut can infect rice at flowering, but symptoms are visible only after panicle exertion. The disease commonly affects the early flowering stage by destroying the pistil.

High nitrogen fertilizer inputs together with rain or high humidity favor false smut disease development. The spores can be carried by wind, and polycyclic infection is possible.

While not offering complete suppression to false smut, 50–75% small gall reduction was observed in previous tests using triazole fungicides, mainly Propiconazole. In this test, triazole fungicides containing propiconazole and difenoconazole were used. Generally, sufficient water volume to deliver fungicides, in addition to spray droplet size, is one of the main criteria to increase coverage and provide the intended level of disease suppression from fungicides. Therefore, the objective of this experiment was to test two commercially available fungicides with different carrier water volumes to determine levels of suppression to sheath blight and false smut in rice.

Procedures

A second year of field plots was established in 2020 for both sheath blight and false smut at the University of Arkansas

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System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas. The cultivars CL163 and Diamond were selected for their susceptibility to sheath blight and false smut, respectively. The cultivar CL 163 was planted on 17 April for sheath blight, and Diamond was planted on 21 May 2020 for false smut. Differences in planting dates depended on the favorability of timing for a high level of disease pressure. Both varieties were drill-seeded with an 8-row planter in 30 ft by 5 ft strip plots. The trials were a randomized complete block design with four replications with two factors: fungicide and carrier water volume.

In both experiments, plots received urea a day prior to permanent flood, at 105 lb N/ac, as well as a mid-season application of 45 lb N/ac. Galls collected in the previous years were crushed and applied during flood establishment to introduce false smut spores. Rice plots were inoculated with corn and rice-based *R. solani* AG1-1A inoculum between panicle initiation and panicle differentiation to artificially establish sheath blight disease. Two 16-fl oz cups full of the inoculum (~ 200 g) were hand-broadcasted over each plot followed by a gentle sweep using a PVC pipe approximately 1.3 in. OD (outside diameter) to knock down the inoculum from foliage into the flood water so the infection could start from the waterline.

Amistar Top and Quilt Xcel were applied 5 days after sheath blight inoculation at 15 and 21 oz/ac, respectively, using two carrier water volumes of 3 and 10 gallons per acre (GPA). Fungicide application for the false smut plots was at mid boot stage. MudMaster™ model MM2013 was used to deliver the fungicides using the two volumes of water with two sets of different nozzle types, sizes, and spray pressures (3 GPA, TDXL110005 at 40 PSI; 10 GPA, AM11001 at 30 PSI). Sheath blight disease progress data were collected three times during the season, i.e., 21 and 28 days after the fungicide application (DAA) and 2 weeks prior to anticipated timing to harvest. The 0 to 9 scale was used to estimate vertical disease progress, where 0 is no disease and 9 indicated disease at flag leaf. Horizontal disease spread was estimated using the percentages of plants with sheath blight lesions in an approximately 3-ft length of the middle two rows of each plot. The disease index was calculated by multiplying the vertical disease progress with the horizontal progress. Sheath blight disease indices were analyzed statistically using PROC GLM procedure in SAS v. 9.4 (SAS Institute, Inc., Cary N.C.). In false smut plots, fungicides rates, water volumes, and all other field management practices were similar to the plots for sheath blight. Percentages of panicles infected with false smut were calculated from an 8-ft^2 area from each plot of 150 ft^2, and the means were compared.

To better understand spray dynamics from these applications, droplet size and droplet velocity were determined. An Oxford Laser VisiSize P15 image particle analyzer was used to measure spray droplet size and velocity in a research-track spray chamber utilizing corresponding application parameters and fungicides from the field experiment. In brief, the system measures droplets and velocities through a paired image shadowgraphy technique (Butts et al., 2018). A minimum of 2,500 individual droplets was measured per replicate with 3 total replications being conducted for a grand total of 7,500 individual droplets being measured. The Dv0.5 (droplet diameter that represents 50% of the spray volume comprised of droplets with a smaller diameter) and velocity were measured, and spray classifications were assigned based on the guidelines from the ASABE/ANSI S572.1 standard (ANSI/ASABE, 2020).

Results and Discussion

The sheath blight data analysis from the field test of 2020 showed a significant difference between the sprayed and unsprayed plots. However, there was no significant difference in efficacy between Amistar Top and Quilt Xcel in the degree of sheath blight suppression. Both fungicides had nearly similar activity on *R. solani* AG1-1A (Fig. 1). In both Amistar top and Quilt Xcel, the Azoxystrobin equivalent was a 12 oz/ac rate. Sheath blight in unsprayed plots showed progression throughout the season, followed by the plots sprayed with 3 GPA. The highest suppression of the disease was in plots that received fungicides sprayed using 10 GPA of water. Attempts were made to harvest the research trial; however, due to tropical storm "Laura" followed by "Delta," rice had significant lodging and sprouting problems and caused erratic yields. Hence, yield data were omitted from this report. This report presents the second year of disease data. The data trends in 2019 and 2020 are in agreement with the need and prominence of adequate coverage to increase fungicide efficacy in suppressing sheath blight.

However, in false smut plots, there were no significant differences between the sprayed and unsprayed plots in the number of galls counted in panicles collected from an 8-ft^2 area inside a plot. Differences between the fungicides and the water amounts used to deliver them were not significant either. Although not significant, the unsprayed check had a lower gall count than the sprayed treatments (Fig. 2). Since these results were far from what was expected, data were collected three times using a different approach. Unfortunately, the trend of all three approaches was similar. The explanation for such unexpected results could be the late planting and the greening effect of the fungicides. These plots were planted 21 May, and plots sprayed with fungicides were visually greener than the unsprayed plots as the season tapered off. The greener the rice, the more chance for secondary infection and hence, the greater gall count. In the year 2019, plots were planted on 16 May, but plots had a low level of false smut, and data were omitted. Although the results of 2020 are also inconclusive, they provided clues that false smut in late-planted rice may be manageable with cultural practices rather than fungicides. Early planted rice usually has less smut, and fungicides may be more effective.

Size and velocity of droplets were compared between the 3 and 10 GPA carrier volumes. The 3 GPA treatment had a greater droplet size than the 10 GPA treatment across fungicides and water alone (Fig. 3). Sprays were all classified as Medium except for Amistar Top and Water alone at 3 GPA, which were Coarse and Very Coarse, respectively. Droplet velocities were also impacted by the application parameters necessary to create spray volume treatments with an approximate 0.5 mph lower droplet velocity for the 3 GPA treatments compared to the 10 GPA treatments (Fig. 4). The increase in spray droplet size and reduction in velocity from the 3 GPA treatment may contribute to the lower sheath blight suppression over the rice canopy through reduced coverage and canopy penetration. Results presented from this study are based on ground spray equipment, nozzles, and application dynamics that may not fully correlate to aerial applications. Field tests on both diseases will be repeated in 2021.

Practical Applications

There are times that fungicides may be effectively delivered, but diseases may not be suppressed as intended. Such situations incur application costs and grain yield loss from diseases. There are several factors that play roles in reducing the efficacy of fungicides. Although the development of genetic insensitivities to the fungicides is possible, so far there is no report of fungicide resistance in Arkansas rice. Generally, fungicides protect rice in well-managed fields, provided rate, timing, and other application conditions (such as carrier water volume and droplet size) are adequate.

Acknowledgments

The authors appreciate the funding support from the rice growers of Arkansas administered by the Arkansas Rice Research and Promotion Board and funding from the University of Arkansas System Division of Agriculture.

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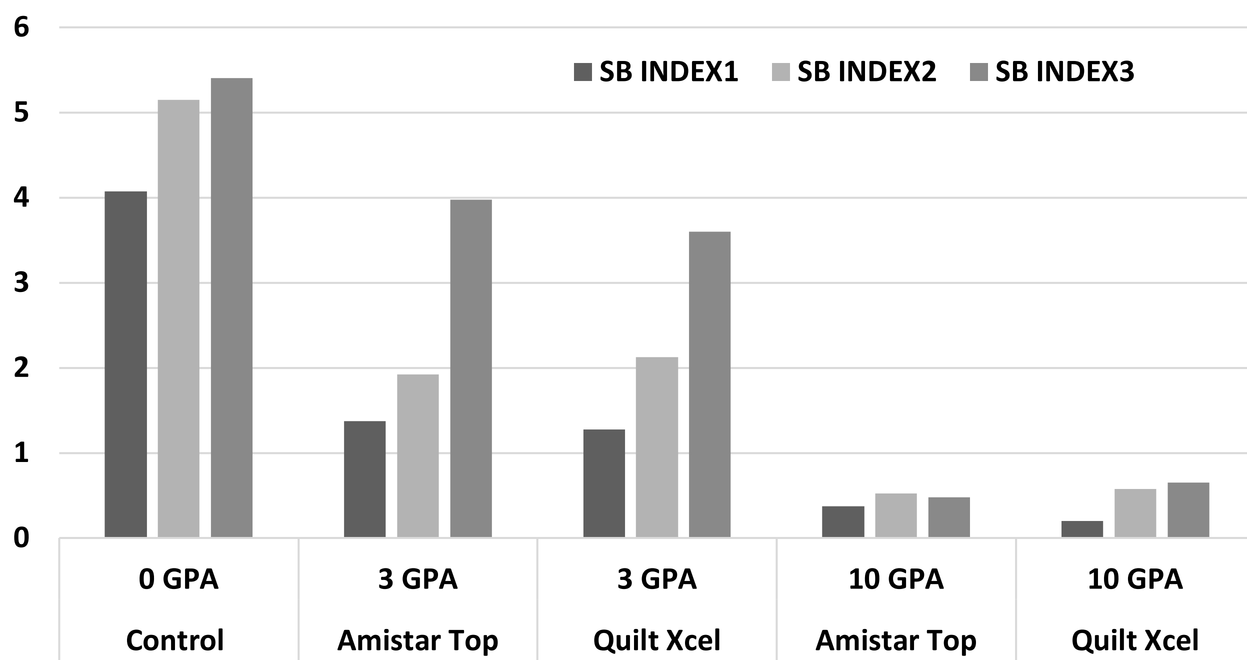

Fig. 1. Sheath blight disease indices (*y*-axis) as collected 21 and 28 days after application (DAA) and two weeks before harvest using Amistar Top (A) at 15 oz/ac and Quilt Xcel at 21 oz/ac using carrier volumes of 3 and 10 gallons per acre (GPA) water in artificially inoculated susceptible rice variety, CL163 in 2020. LSD 0.05 = 0.99, 0.98, 1.73 for 21, 28, and near harvest, respectively.

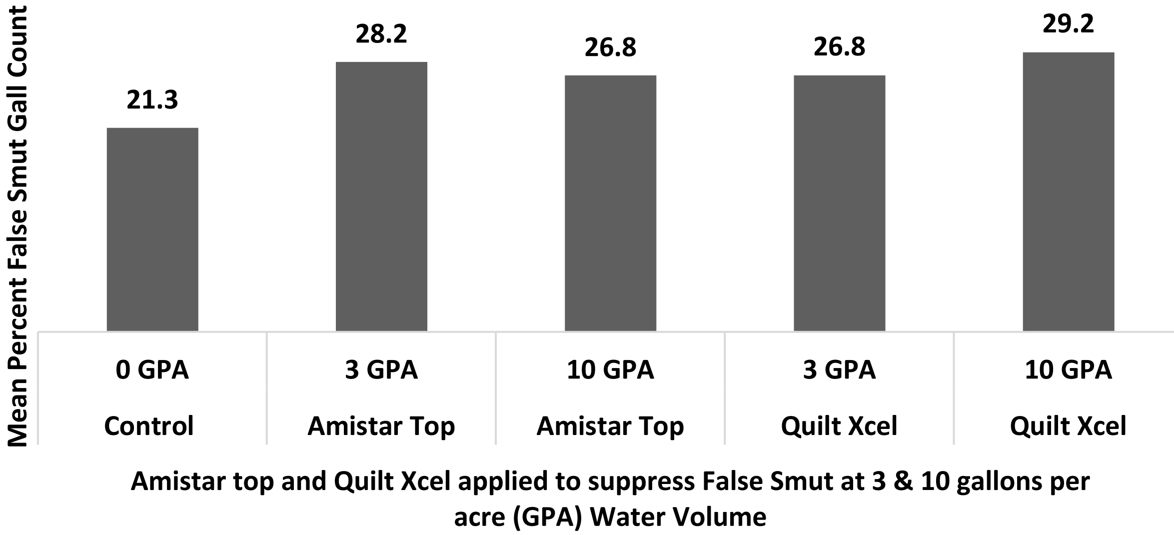

Fig. 2. Percent panicles with one or more false smut galls from rice sampled in an 8-ft² area from a 150-ft² plot in 2020 using Amistar Top (A) at 15 oz/ac and Quilt Xcel at 21 oz/ac in carrier water volumes of 3 and 10 gallons per acre (GPA) sprayed at the mid-boot stage.

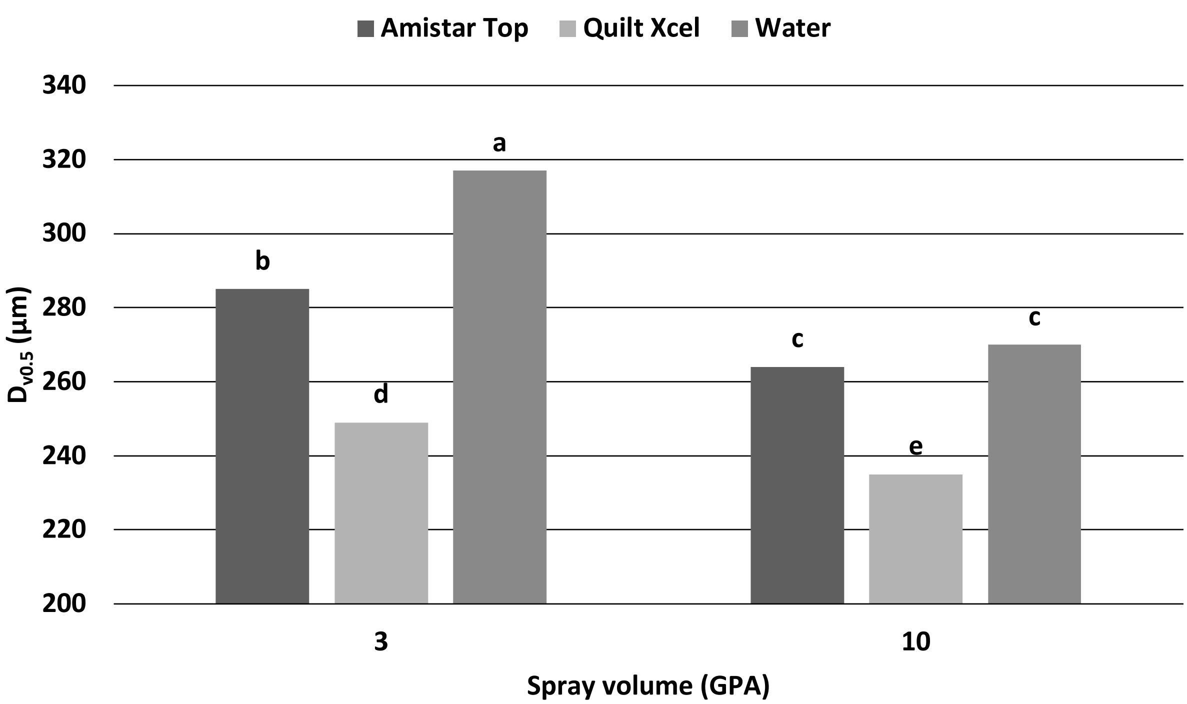

Fig. 3. Droplet size ($D_{v0.5}$) of water and fungicides using the application parameters (nozzle type, size, pressure) to create the spray volume treatments. The $D_{v0.5}$ is the droplet diameter that represents 50% of the spray volume comprised of droplets with a smaller diameter.

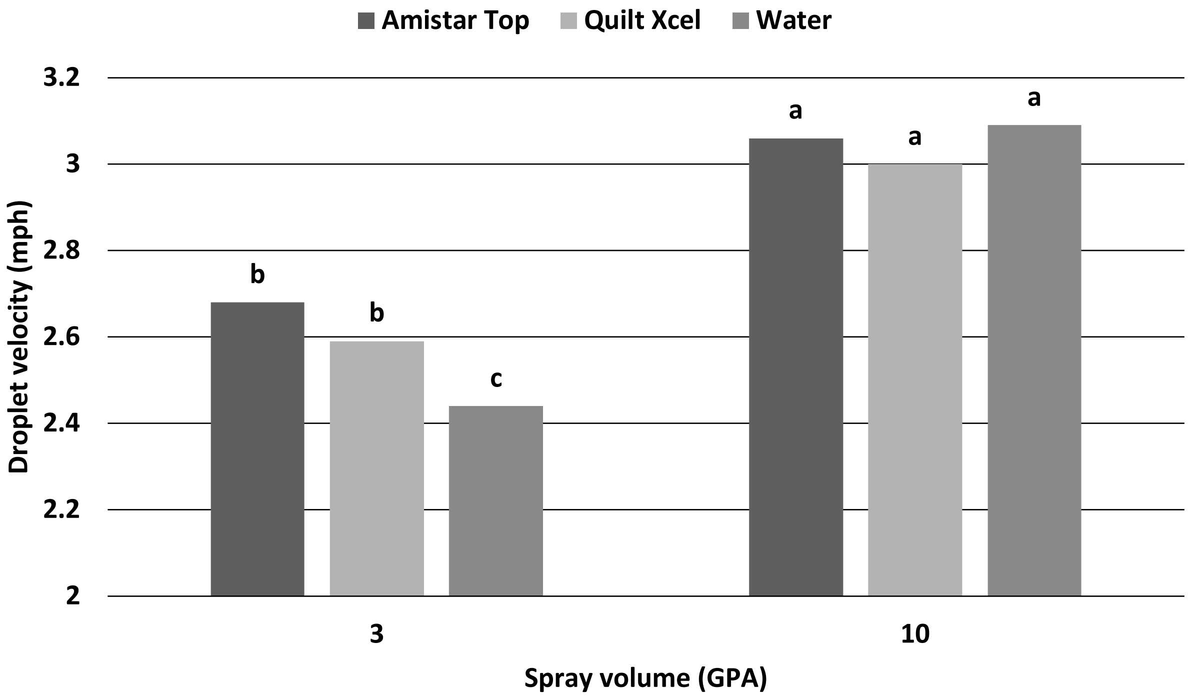

Fig. 4. Droplet velocity (mph) of water and fungicides using the application parameters (nozzle type, size, pressure) to create the spray volume treatments.

Evaluation of Contemporary Rice to Straighthead

Y. Wamishe,[1] J. Hardke,[2] and T. Gebremariam[1]

Abstract

Straighthead has been known to affect a small percentage of the Arkansas rice acreage. However, flooded water from considerable acreage is drained every year to manage straighthead, incurring additional costs to rice production. The major objectives of this study were to provide growers with updated information on the susceptibility of the new rice varieties and hybrids regarding their reaction to straighthead, to re-evaluate the older varieties which are still in production, and to assess the susceptibility of advanced breeding lines prior to their release for commercial production. This paper reports about the procedure and results of the second year field test, and hence, data from 2019 and 2020 tests have been included for comparison. In 2020, two different bays were established in experimental fields of the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), Stuttgart, Arkansas. These bays were planted, each with 36 (31 test entries and 5 control) in four replications in hill plots. Both bays received MSMA (Monosodium Methanearsonate) and one of these two bays was marked for permanent flood up to 4 inches depth starting from 5-leaf up to hard dough stage. The other bay was flushed intermittently. The entries were visually examined for straighthead symptoms between the soft and hard dough stage but before the flood was drained. The bay that received MSMA and kept with permanent flood showed 8 of 31 entries with higher straighthead symptoms, 16 moderate, and 7 low to no symptoms. In the intermittent flushed bay, only the 8 entries that rated high showed mild straighthead symptoms on a few panicles of late tillers. The experiment will be conducted again in 2021 using two concentrations of MSMA.

Introduction

Straighthead in rice (*Oryza sativa*) is one of the oldest reported physiological disorders of unknown cause. Rice florets with straighthead symptoms are commonly sterile, leading to blank rice panicles and hence, a significant decline in grain yield. There may be several factors that contribute to the development of straighthead in different soil types across the rice-growing counties in Arkansas. Unfortunately, once straighthead appears in rice fields, symptoms appear each time rice is grown unless cultivars with some levels of resistance are used. In a field planted with susceptible rice, straighthead may develop at some point during the season unless the field is drained and dried to alleviate the problem with adequate aeration. In order to reduce the impact on grain yield, the drain and dry strategy should be implemented at appropriate timing, usually before the beginning of the reproductive stages.

The drain and dry management strategy is often difficult when field sizes are too big to adequately and timely drain. Moreover, the crop suffers water shortage if water resources are limited to re-flood in a relatively short time. Generally, the use of resistance is cheaper and user-friendly. Rice varieties can be "R"(resistant), "MR" (moderately resistant), "S" (susceptible), "MS" (moderately susceptible), and "VS" (very susceptible) to straighthead. Although straighthead is known to distress a small percentage of the Arkansas rice acreage, growing S or VS cultivars in fields with a history of straighthead results in an adverse loss of grain yield. To date, most Arkansas acreages known to have straighthead are drained and dried before mid-season. However, the more resistance is used, the less the challenge is likely to drain and dry the field, therefore reducing the cost and time of rice producers. The main objectives of this study were to provide rice producers with the most current information regarding the susceptibility of the new rice varieties and hybrids for their reaction to straighthead, to re-evaluate the older varieties that are still in production, and to assess the susceptibility of advanced breeding lines before they are released for commercial production.

Procedures

A field experiment was carried out for the second season at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) to evaluate rice cultivars and advanced breeding lines for resistance or tolerance to straighthead. The plots were in the field that was established over a decade ago to evaluate rice germplasm to straighthead. Before planting, the selected area was measured out and rototilled. A gallon per acre rate of Monosodium Methanearsonate (MSMA) was sprayed using a MudMaster at 20 gallons of water per acre (GPA) rate and was lightly rototilled again to incorporate the arsenate compound with the soil. A couple of hours after incorporation, 36 rice entries consisting of 16 conventional cultivars, 9 advanced breeding lines, 6 Rice Tech hybrid rice, and 5 control entries were planted. The five varieties used as control entries included Cocodrie and CL151 as susceptible, Taggart and RT CLXL745 as resistant, and Francis as moderately resistant. All 36 entries

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were planted in hill plots in 4 replications. The five rice varieties used as control were planted before and after every 15 or 16 test entries. All varieties or lines, including the control entries, were planted adjacently in two similar bays. One of the bays was kept flooded starting from the 5-leaf stage. Flood was raised to at least 4 inches depth as the rice grew up and was maintained until the hard dough stage. On the other hand, the adjacent bay was flushed intermittently following a week of dryness. Visual comparisons were made between each entry in reference to the responses of the varieties used as control. A 0 to 9 scale was used where 0 is no symptoms and 9 primary and secondary tillers with typical symptoms of straighthead.

Results and Discussion

The susceptible control entries (CL151 and Cocodrie) showed high-level straighthead symptoms in the bay with permanent flood than the bay that was intermittently flushed. Likewise, some entries showed symptoms in the flooded bay than the flushed bay. Straighthead symptoms were hardly seen on main tillers in the flushed bay. The bay that received MSMA and kept with permanent flood showed 8 of 31 entries with high straighthead symptoms, 16 moderate, and 7 entries with low or no symptoms. In the bay that was kept flushed and received MSMA, only those 8 entries that had the highest rating, i.e., >6 in the flooded bay, showed some level of straighthead in panicles of late tillers (Table 1). When data of 20 entries from 2020 were compared to similar entries in 2019 (in bold, Table 1), there were limited differences. These differences likely were caused by variations in flood depth and hence, severity levels of anaerobic conditions. Generally, information regarding the response of commercial rice varieties to straighthead is important to rice producers as they make early decisions on varietal selection, water use, and anticipation to costs that may be incurred by the "drain and dry strategy'. The test will be repeated for another season in 2021.

Practical Applications

Using the "drain and dry" strategy to manage straighthead is difficult in fields that are big, where water is limited and pump capacity is unable to re-flood the field in a relatively short period of time. However, if the information regarding the responses of commercial varieties to straighthead is fully known, planting resistant or moderately resistant varieties is always the best and most user-friendly alternative strategy to prevent significant losses that may have occurred due to this physiological disorder.

Acknowledgments

The authors appreciate the funding and support from the Arkansas rice producers through monies administered by the Arkansas Rice Research and Promotion Board, and the University of Arkansas System Division of Agriculture.

Table 1. Reactions of rice cultivars to monosodium methanarsenate (MSMA) in field tests at the Rice Research and Extension Center, Stuttgart, Arkansas in 2019 and 2020.

Entry #[a]	Cultivar[b]	Previous Reaction	2019 Reaction 0–9 scale	Entry #	Cultivar	2020 Reaction 0–9 scale
1	**ARoma 17**	**-**	**9**	**1**	**ARoma 17**	**6**
2	**CL111**	**S**	**9**	**3**	**CL111**	**7**
3	**CL153**	**--**	**9**	**4**	**CL153**	**8**
8	**Diamond**	**--**	**4**	**9**	**Diamond**	**4**
10	**Jupiter**	**S**	**1**	**13**	**Jupiter**	**5**
19	**Titan**	**MS**	**5**	**14**	**Titan**	**5**
26	**CLL15**	**S**	**5**	**5**	**CLL15**	**6**
30	**RU1701087**	**-**	**9**	**10**	**Jewel (ARX7-1087)**	**8**
25	**RU1701121**	**-**	**4**	**15**	**Lynx (ARX7-1121)**	**5**
29	**RU1701084**	**-**	**4**	**11**	**ProGold1 (ARX7-1084)**	**5**
28	**RU1701081**	**-**	**5**	**12**	**ProGold2 (ARX7-1081)**	**7**
24	**RU1701185**	**--**	**1**	**26**	**RU1701185**	**6**
21	**RU1901133**	**-**	**1**	**23**	**RU1901133**	**3**
23	**RU1801169**	**MS**	**4**	**25**	**RU1801169**	**6**
22	**RU1801101**	**-**	**Missing**	**24**	**RU1801101**	**6**
16	**RT Gemini 214 CL**	**-**	**4**	**17**	**RT Gemini 214 CL**	**5**
18	**RT XP753**	**-**	**4**	**18**	**RT XP753**	**4**
17	**RT XP113**	**-**	**4**	**20**	**RT 7501 (XP 113)**	**6**
9	**Jazzman-2**	**--**	**Missing**	**2**	**Jazzman-2**	**8**
27	**CLM04**	**-**	**4**	**16**	**CLM04**	**4**
13	PVL01	-	4	8	PVL02	5
4	CL163	--	7	19	RT 7301	0
5	CL172	--	1	21	RT 7321 FP	6
6	CL272	--	7	22	RT 7521 FP	3
7	Della-2	--	9	6	CLL16	6
11	LaKast	MS	4	7	CLL17	7
12	Mermentau	VS	9	27	RU1701121	5
14	Rex	S	8	28	RU1701127	3
15	Roy J	S	4	29	STG18P-01-231	7
20	Wells	-	9	30	RU1601010	7
				31	RU1801145	6
C1	CL151	VS	9	C1	CL151	8
C2	Cocodrie	VS	9	C2	Cocodrie	7
C3	Francis	MR	5	C3	Francis	4
C4	XL745	R	1	C4	XL745	1
C5	Taggart	R	1	C5	Taggart	3

[a] Entries from 2019 are in bold type.

[b] C1, C2, C3, C4 and C5 were cultivars used as control in both years.

Arkansas Rice Stink Bug Threshold Reevaluation

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Abstract

Thresholds for rice stink bug have changed in recent years for multiple states in the southern rice-growing region. Many of these thresholds have been lowered; however in Arkansas, the threshold has not changed. Studies were conducted at three locations in 2020 to reevaluate the current rice stink bug threshold. The current threshold, 5 rice stink bugs per 10 sweeps during the first two weeks of heading and 10 rice stink bugs per 10 sweeps during the second two weeks of heading, were compared to 10 rice stink bugs per 10 sweeps and an untreated control. No yield or milling differences were observed among the different thresholds. At two of the 3 locations, the standard threshold and 10 all-season thresholds reduced rice stink bug peck and total peck compared to the untreated control. This data suggest that our current threshold is still maintaining profitability for growers but needs further evaluation.

Introduction

In the southern United States, rice stink bug (*Oebalus pugnax* F.) is the major pest of heading rice. Rice stink bug feeds on the developing seed of multiple types of grass and grass crops. When rice stink bug feeds on flowering and milk stage rice kernels, these kernels are aborted, causing direct yield loss (Webb, 1920). Rice stink bug can also cause indirect or quality loss in rice when feeding occurs during the soft and hard dough stages. During these stages, feeding from rice stink bug causes the grain to become broken, shrunken, and discolored. This damage is referred to as 'peck' or 'pecky rice' and can lead to price reductions when growers sell the grain (Swanson and Newsom, 1962).

Over the past 5 years, rice stink bug thresholds have changed in multiple states throughout the southern rice-growing region. In Arkansas, the rice stink bug threshold has not changed. The current threshold is 5 rice stink bugs (nymphs plus adults) per 10 sweeps during the first two weeks of heading and 10 rice stink bugs per 10 sweeps during the second two weeks of heading (Lorenz et al., 2018). Rice stink bug applications can be terminated at 60% hard dough (straw-colored kernels). In Mississippi and Louisiana, the threshold during the first two weeks of heading has been reduced; however, Texas has moved to a dynamic threshold that in general is higher across all heading growth stages than Arkansas. With these changes occurring to surrounding state's thresholds, it is imperative that we reevaluate our current threshold to ensure growers maintain profitability.

Procedures

Experiments to evaluate multiple rice stink bug thresholds were conducted in 2020 at 3 locations in Arkansas: Almyra, Stuttgart, and Ulm. These experiments were conducted on grower fields; therefore agronomic practices and cultivar varied between locations. At each location, 3 thresholds were compared: an untreated check (never sprayed for rice stink bug); our current threshold of 5 rice stink bugs per 10 sweeps during the first two weeks of heading and 10 rice stink bugs per 10 sweeps during the second two weeks of heading; and a 10 rice stink bugs per 10 sweeps all season. Each plot was sampled weekly, from the flowering growth stage through 60–70% hard dough, by conducting 2 sets of 10 sweeps per plot. When a threshold was met or exceeded, a foliar application of 3.65 oz/ac of Lambda-Cy (Lambda cyhalothrin) was made using a backpack sprayer equipped with TeeJet® TX-6 hollow cone nozzles, calibrated to 10 GPA. Plot size was 20 ft by 50 ft, and plots were arranged as a randomized complete block with four replications at each location. All plots were harvested using a Wintersteiger® combine, and yield was calculated at 12% moisture. After grain drying, total rice and head rice was determined using a McGill® grain mill. All data were analyzed using PROC GLIMMIX SAS v 9.4 (SAS Institute, Inc., Cary N.C.).

Results and Discussion

No differences were observed between the different thresholds with respect to yield, total rice, or head rice (Table 1). At the Ulm and Stuttgart locations, the standard threshold and the 10 all-season threshold reduced both rice stink bug peck and total peck compared to the untreated control. No differences were observed among treatments for either rice stink bug peck or total peck among treatments for the Almyra location. Only the Ulm and Stuttgart locations exceeded 2.5% peck, the point at which growers would be penalized, in the untreated check (Table 2).

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Practical Applications

With the recent changes in rice stink bug threshold throughout the southern rice-growing region, along with the increase in inputs to grow a rice crop, it is important we ensure our current rice stink bug threshold is maintaining profitability for our growers. Similar trends were observed in the 2020 studies compared to Cato et al. (2019) and Bateman et al. (2020), suggesting that our current threshold is sufficient in protecting growers from yield and quality loss from rice stink bug.

Acknowledgments

The authors would like to express their appreciation to the Arkansas Rice Checkoff Program administered by the Arkansas Rice Research and Promotion Board, the University of Arkansas System Division of Agriculture, and all of the cooperators that allowed us to use their land.

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Table 1. Yield and milling yields for multiple rice stink bug thresholds.

Threshold	bu./ac	%TR†	%HR‡
Untreated	162.2 (3.1) a§	66.1 (0.6) a	50.4 (1.3) a
Standard	166.8 (3.3) a	66.5 (0.4) a	50.9 (1.3) a
10 All Season	168.5 (4.2) a	67.1 (0.7) a	50.4 (1.1) a
***P*-value**	0.21	0.46	0.51

† Percent total rice.

‡ Percent head rice.

§ There is no significant difference between any treatment for any of the factors.

Table 2. Rice stink bug and total peck analysis for multiple rice stink bug thresholds at 3 locations in Arkansas, 2020.

	Location					
	Almyra		Stuttgart		Ulm	
Threshold	RSB†	Total	RSB	Total	RSB	Total
Untreated	2.4 (0.6) a‡	2.5 (0.4) a	4.8 (0.6) a	4.8 (0.6) a	3.0 (0.1) a	3.1 (0.2) a
Standard	2.2 (0.3) a	2.3 (0.3) a	3.3 (0.2) b	3.3 (0.2) b	1.6 (0.2) b	1.7 (0.1) a
10 All Season	2.5 (0.4) a	2.6 (0.6) a	2.9 (0.3) b	3.0 (0.3) b	1.9 (0.2) b	2.1 (0.3) a
***P*-value**	0.29	0.31	<0.01	<0.01	<0.01	0.01

† Rice stink bug peck.

‡ Means followed by the same letter are not significantly different at $\alpha = 0.05$.

Comparing Insecticide Impregnated Urea to Insecticide Seed Treatments for Control of Rice Water Weevil

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Abstract

Grape colaspis and rice water weevil are major pests of rice in Arkansas. The larvae of these pests feed on the root system of the rice plant. Grape colaspis damages rice prior to flood, and rice water weevil feed on rice after permanent flood establishment. The main control strategy for these pests is the use of insecticide seed treatments. For rice water weevil, foliar insecticide applications are also a control option but typically are less consistent than insecticide seed treatments. Insecticide impregnated urea has proven to be an effective control option for rice water weevil but has not been evaluated with currently labeled insecticides. A study was conducted in 2020 at two locations comparing insecticide seed treatments and insecticide-treated urea for control of rice water weevil. An increase in rice water weevil control and yield was observed for insecticide-treated urea compared to the untreated control; however, insecticide seed treatments provided more consistent control and yield increases compared to treated urea. These studies suggest that insecticide-impregnated urea could be a control option for rice water weevil, but more work is needed to determine the correct product and rate for more efficient control.

Introduction

In Arkansas, there are multiple soil pests that feed on rice plants. Of these pests, grape colaspis (*Colaspis brunnea*) and rice water weevil (*Lissorhoptrus oryzophilus*) are the most economically important (Lorenz et al., 2018). Grape colaspis larvae feed on seedling rice, typically causing plant death and stand loss. Rice water weevil adults are attracted to flooded rice and migrate to the field shortly after permanent flood establishment. The adult rice water weevils feed on rice leaves, leaving linear feeding scars. This feeding is superficial and causes no yield loss; however, the larvae of rice water weevils can cause tremendous yield loss at high densities. Rice water weevil larvae feed on the roots of rice plants, causing root pruning, and in severe cases, plant death (Lorenz et al., 2018).

Insecticide seed treatments and foliar insecticide applications are the main control strategies for grape colaspis and rice water weevil (Hummel et al., 2014; Thrash et al., 2020). CrusierMaxx Rice and NipsIt Inside are the most commonly used insecticide seed treatments in rice. Both of these products are neonicotinoids and are highly efficacious on grape colaspis. They provide control of rice water weevil as well but can be less consistent than other treatments. Neonicotinoid seed treatments typically only last 28–35 days after planting. In many cases, rice planted in April will take 45–60 days to get to permanent flood. By this point, these seed treatments are no longer providing sufficient control of rice water weevil. The diamide seed treatments, Dermacor X-100 and Fortenza, have a longer residual than neonicotinoid seed treatments, and provide consistent control of rice water weevil, but neither are as efficacious on grape colaspis as CruiserMaxx Rice or NipsIt Inside. Foliar insecticides can be effective at controlling rice water weevils if timely applications are made; however, foliar applications are less consistent than insecticide seed treatments.

Rice is fertilized prior to flooding with nitrogen in the form of urea. Impregnating a pesticide on urea has been evaluated for control of multiple pests in rice (Bond et al., 2007), including rice water weevil (Way and Wallace, 1996). While the impregnated urea was effective at controlling rice water weevil, these studies used chemistry that is no longer labeled for use in rice. The objective of this study was to determine if impregnating urea with insecticides provides adequate control of rice water weevils compared to insecticide seed treatments.

Procedures

An experiment was conducted in 2020 at the University of Arkansas System Division of Agriculture's Rice Research and Experiment Station (RREC) near Stuttgart, Arkansas, and Pine Tree Research Station (PTRS) near Colt, Arkansas. Diamond was planted at the RREC location on 17 April, and RT7301 was planted at PTRS on 4 May. Multiple insecticide seed treatments, including a fungicide only (UTC) (Table 1), were compared to chlorantraniliprole (Prevathon) at 14 oz/ac, Clothianidin (Belay) at 4 oz/ac, and Zeta-Cypermethrin (Mustang) at 4 oz/ac impregnated on urea. Rice water weevil densities were evaluated 33 and 21 days after permanent flood establishment for the RREC and

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PTRS respectively. Larval densities were determined by taking 3 core samples per plot with a 4-inch core sampler. Core samples were then washed through a series of sieves and examined in a saltwater solution. All rice water weevil larvae were counted per plot. Data were processed in Agriculture Research Manager v. 10, with an analysis of variance, and Duncan's New Multiple Range Test ($P = 0.10$) to separate means.

Results and Discussion

Rice Water Weevil Control

At the RREC location, all treatments except the clothianidin-treated urea treatment reduced rice water weevil densities compared to the UTC. Zeta-cypermethrin-treated urea lowered rice water weevil densities compared to the UTC and clothianidin-treated urea but was higher than all insecticide seed treatments and chlorantraniliprole-treated urea (Fig. 1).

At the PTRS location, all treatments, except the zeta-cypermethrin-treated urea, reduced rice water weevil densities lower than the UTC. Fortenza insecticide seed treatment reduced rice water weevils compared to CruiserMaxx Rice and zeta-cypermethrin-treated urea (Fig. 2).

Grain Yield

Chlorantraniliprol-treated urea and Fortenza insecticide seed treatment yielded lower than Dermacor and CruiserMaxx insecticide seed treatments, as well as clothianidin and zeta-cypermethrin-treated urea at the RREC location. Additionally, NipsIt Inside insecticide seed treatment and the UTC treatments did not differ from any treatments (Fig. 3).

At the PTRS location, all treatments yielded higher than the UTC. Chlorantraniliprole treated urea yielded higher than chlothianidin treated urea, zeta-cypermethrin treated urea, and CruiserMaxx Rice insecticide seed treatment. Fortenza, Dermacor X-100, and NipsIt Inside insecticide seed treatments did not differ from any other insecticide treatment with respect to yield (Fig. 4).

Practical Applications

Across both locations, insecticide seed treatments provided more consistent control of rice water weevil than insecticide treated urea, with the exception of chlorantraniliprole treated urea. A similar trend was observed for yield. This data suggest that insecticide-treated urea could be a control option for growers to control rice water weevils, but more work is needed to determine the best product, rate, and timing for this strategy. For now, growers can expect more consistent control and increased yields with insecticide seed treatments compared to insecticide-treated urea.

Acknowledgments

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Table 1. List of insecticide seed treatments and rates in the experiments at the University of Arkansas System Division of Agriculture's Rice Research and Experiment Station (RREC) near Stuttgart, Arkansas, and Pine Tree Research Station (PTRS) near Colt, Arkansas.

Insecticide Seed Treatment	Rate	Insecticide Class
Fungicide Only (UTC)[a]		
CruiserMaxx Rice	7 oz/cwt	Neonicotinoid
NipsIt Inside	1.9 oz/cwt	Neonicotinoid
Dermacor X-100	2.5 oz/cwt (RREC) 5 oz/cwt (PTRS)	Diamide
Fortenza	3.47 oz/cwt	Diamide

[a] UTC = untreated control.

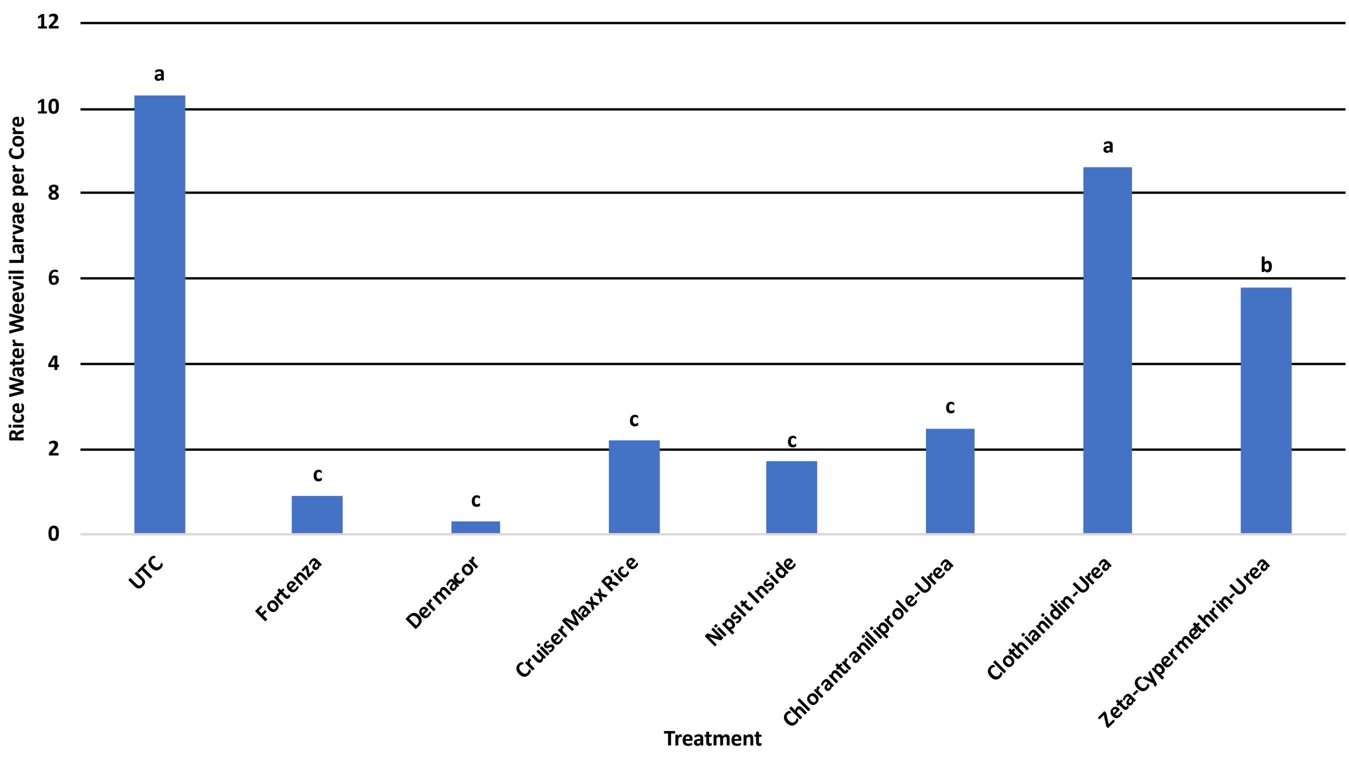

Fig. 1. Rice water weevil control comparing multiple insecticide seed treatments and insecticide-impregnated urea to a fungicide only treatment (UTC = untreated control) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, 2020.

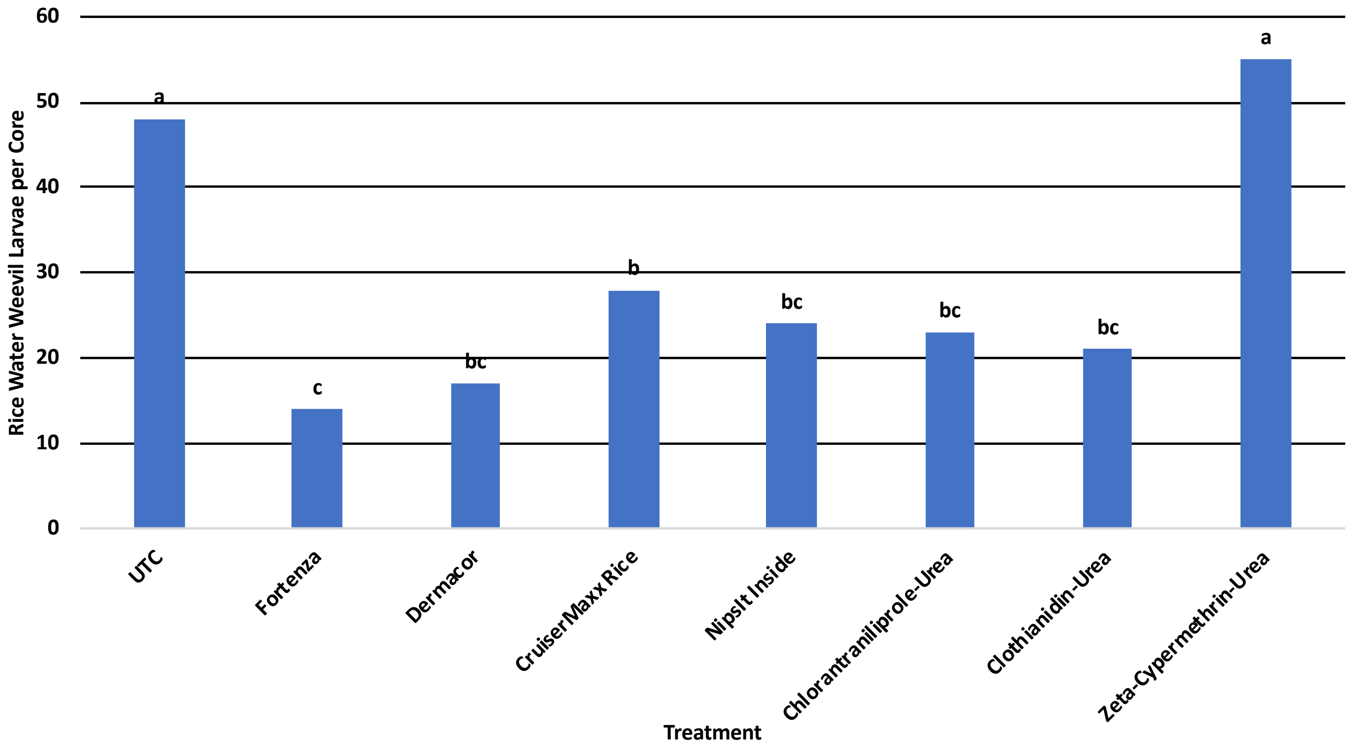

Fig. 2. Rice water weevil control comparing multiple insecticide seed treatments and insecticide-impregnated urea to a fungicide only treatment (UTC = untreated control) at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, Colt, 2020.

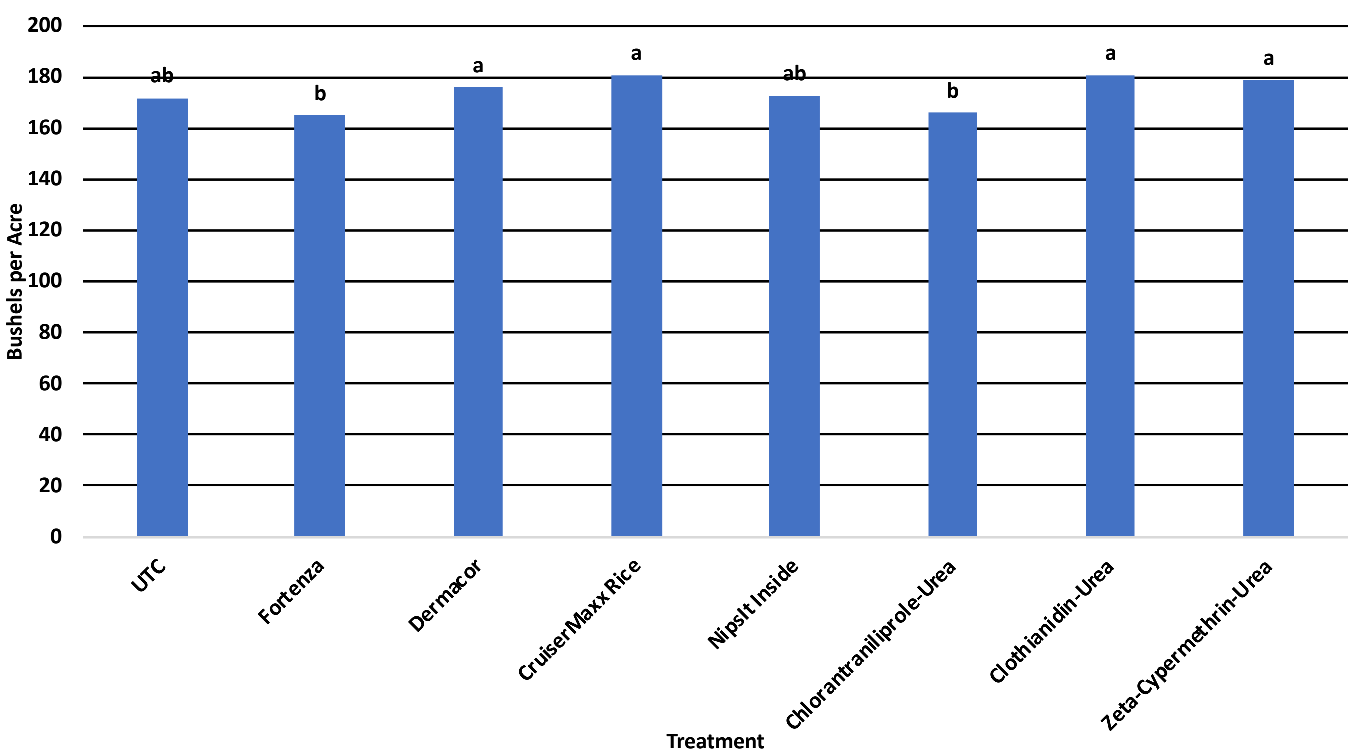

Fig. 3. Rice grain yield comparing multiple insecticide seed treatments and insecticide-impregnated urea to a fungicide only treatment (UTC = untreated control) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, 2020.

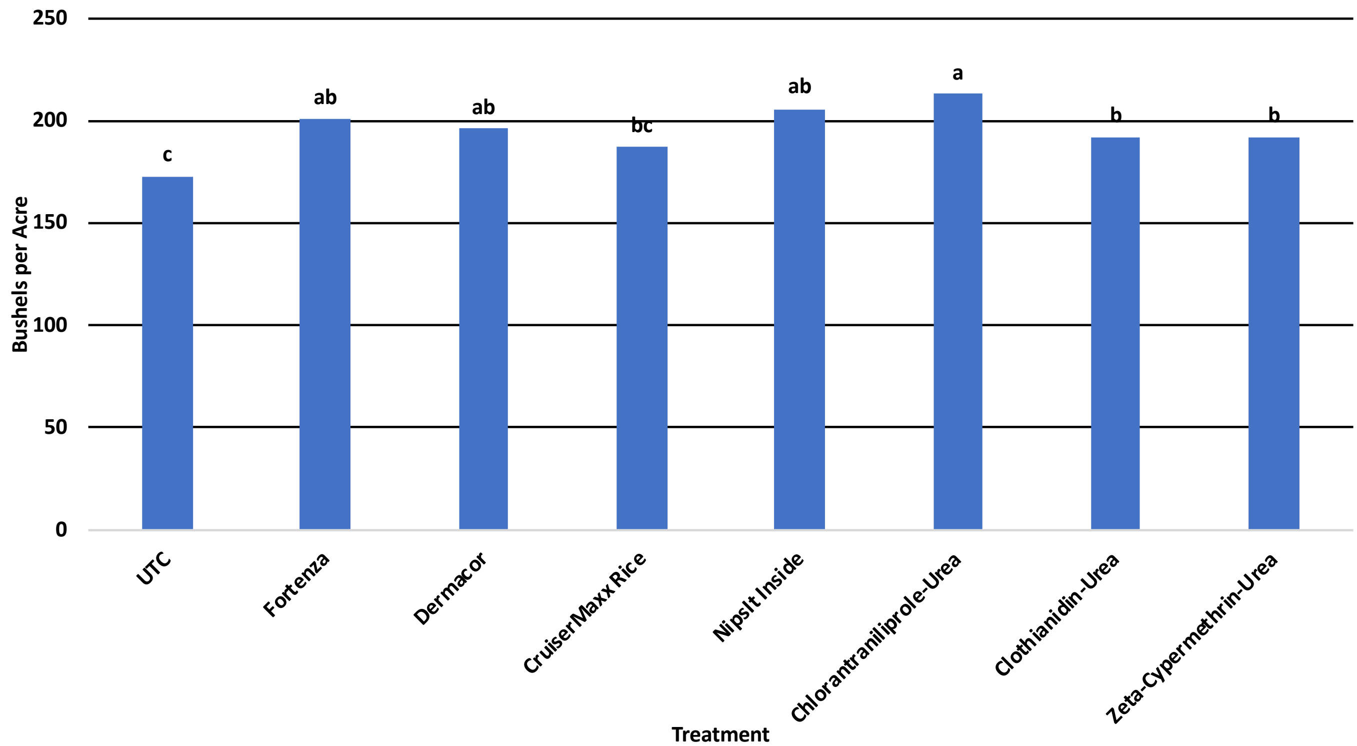

Fig. 4. Rice grain yield comparing multiple insecticide seed treatments and insecticide-impregnated urea to a fungicide only treatment (UTC = untreated control) at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, Colt, 2020.

Development of Defoliation Thresholds in Rice

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Abstract

Armyworms are commonly found in rice fields in the mid-southern U.S. and have the potential to cause severe defoliation to the rice crop. The two main armyworm species observed in rice in this region are true armyworms and fall armyworms. It is common to see infestations occur at all growth stages of rice. The current threshold for armyworms in rice is based on the number of larvae per square foot. A defoliation-based threshold would provide growers and consultants with a simple way to make economically sound decisions for controlling armyworms in rice. Studies were conducted in 2019 and 2020 where rice was mechanically defoliated at 0%, 33%, 66%, and 100% with a weed eater at 2-3 leaf, early tiller, late tiller, and green ring growth stages across three planting dates. Large amounts of yield loss were observed when plants were defoliated either 66% or 100% at the green ring growth stage. A delay in heading was also observed when plants were defoliated at 66% or 100% during any growth stage in 2019. Maturity delays were also observed in 2020 but were not as severe as what was observed in 2019. Yield losses were greatest in the May planting date; however, delays in heading were greater for the June planting date. This data has helped form a defoliation-based threshold in rice to help keep rice growers profitable.

Introduction

Armyworms are an occasional pest of rice in the mid-south. The two most common species of armyworms in rice production are true armyworms (*Psuedoletia unipuncta*) and fall armyworms (*Spodoptera frugiperda*) (Lorenz et al., 2018). Infestations of armyworms can cause substantial damage to rice plants. Typically this damage is isolated to the edges of fields, but in some cases, large portions of fields can experience high levels of defoliation. Armyworms can infest rice at any point during the growing season. When infestations occur at early growth stages, it is common to see rice plants defoliated all the way to the soil line or water level if the permanent flood is established. The current threshold for armyworms in rice is based on the number of larvae per square foot, which can be difficult to determine for growers and consultants. A defoliation-based threshold would be easier to use and a better option for growers. The objective of this study was to determine the impact of defoliation on the yield and growth of rice across multiple planting dates and growth stages, and to determine a defoliation-based threshold for rice.

Procedures

Studies were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Arkansas, in 2019 and 2020 to determine the impact defoliation has on rice across multiple planting dates. Diamond was drill seeded at 70 lb/ac on 8 April, 1 May, and 1 June. Plots were 8 rows (7.5-in. spacing) by 16.5 ft. Defoliation was simulated using an electric weedeater at the 2-3 leaf, early tiller, late tiller, and green ring growth stages. Plots were defoliated either 0%, 33%, 66%, or 100%. The 100% defoliation level at the 2-3 leaf growth stage was defoliated all the way to the soil line, but for all other growth stages, the 100% defoliation was defoliated to the water line. Plots were arranged in and randomized complete block design with 6 replications within each planting date. Days to 50% heading were recorded for all plots to determine maturity delays associated with defoliation. Data were analyzed with PROC GLIMMIX SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with an alpha level of 0.05.

Results and Discussion

No yield loss was observed for the 2-3 leaf, early tiller, or late tiller growth stages for the April planting, although major yield losses were observed for the green ring defoliation timing (Fig. 1). A similar trend was observed for May and June plantings for the 2-3 leaf and early tiller growth stages (Figs. 2 and 3). In the May and June plantings, yield losses associated with defoliation at the late tiller growth stage were similar; however, yield losses were greater for the may planting at the green ring growth stage compared to the June planting.

No heading delays were observed for the 2-3 leaf growth stage for any planting date in 2019; however in 2020, at the June planting, a short delay in maturity was observed. Heading delays were observed for high levels of defoliation at the early tiller growth stage in 2019, but delays were only observed for the June planting in 2020. For both the late tiller growth stage and green ring growth stage, heading delays were observed for the May and June plantings in both years, with greater delays being observed in 2019 compared to 2020 (Table 1).

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Overall, defoliation did not severely impact yield or maturity for the April planting unless the defoliation occurred at the green ring growth stage. The May and June plantings were impacted worse than the April planting, with major yield loss and heading delays observed when defoliation occurred during the late tiller or green ring growth stages. Temperature effects could account for the difference in yield loss at the green ring growth stage between May and June plantings, as well as heading delay observed between 2019 and 2020. Further analysis of heat units is needed to determine what impact temperature has on the recovery of rice after a defoliation event occurs.

Practical Applications

These data have allowed us to develop a defoliation-based threshold that will ensure growers stay profitable. The new defoliation-threshold in rice is that no applications are needed for 2-3 leaf and early tiller growth stages across all plantings; but if the soil is cracking and armyworms can feed on the growing point, then applications may be warranted. For May and June plantings, applications are needed if defoliation exceeds 40% at the late tiller growth stage or if defoliation exceeds 20% at green ring. Applications may also be needed if head clipping is occurring in heading rice. These thresholds will eliminate unwarranted sprays for early season defoliation, as well as for small amounts of defoliation observed at later growth stages. The elimination of these insecticide applications will also help preserve beneficial insects that aid in the control of major pests, such as rice stink bugs.

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The authors would like to express their appreciation to the Arkansas Rice Checkoff Program administered by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture.

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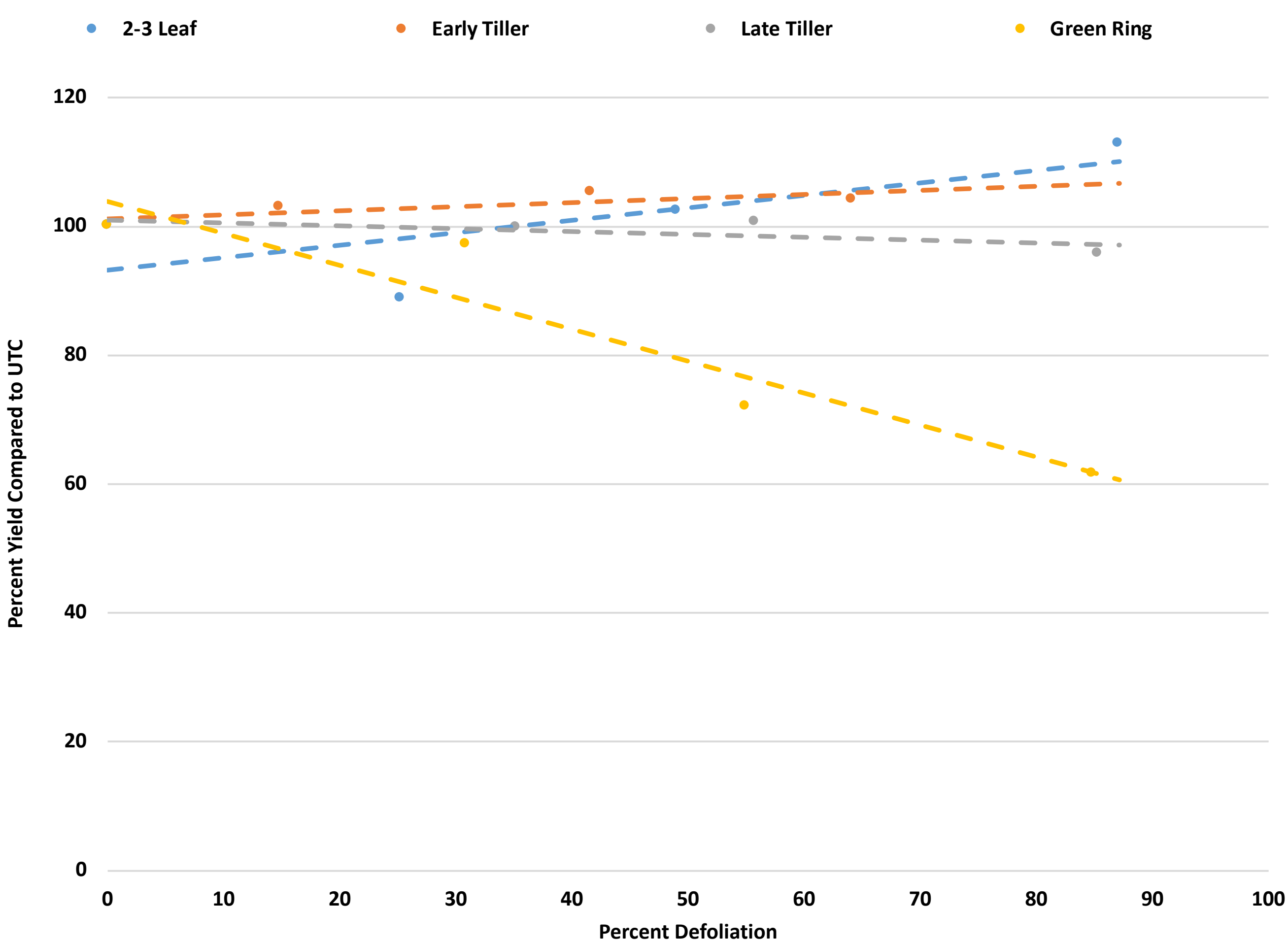

Fig. 1. Yield impacts caused by varying levels of defoliation for studies conducted in 2019 and 2020 at multiple growth stages for April-planted rice, at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Arkansas. UTC = untreated control.

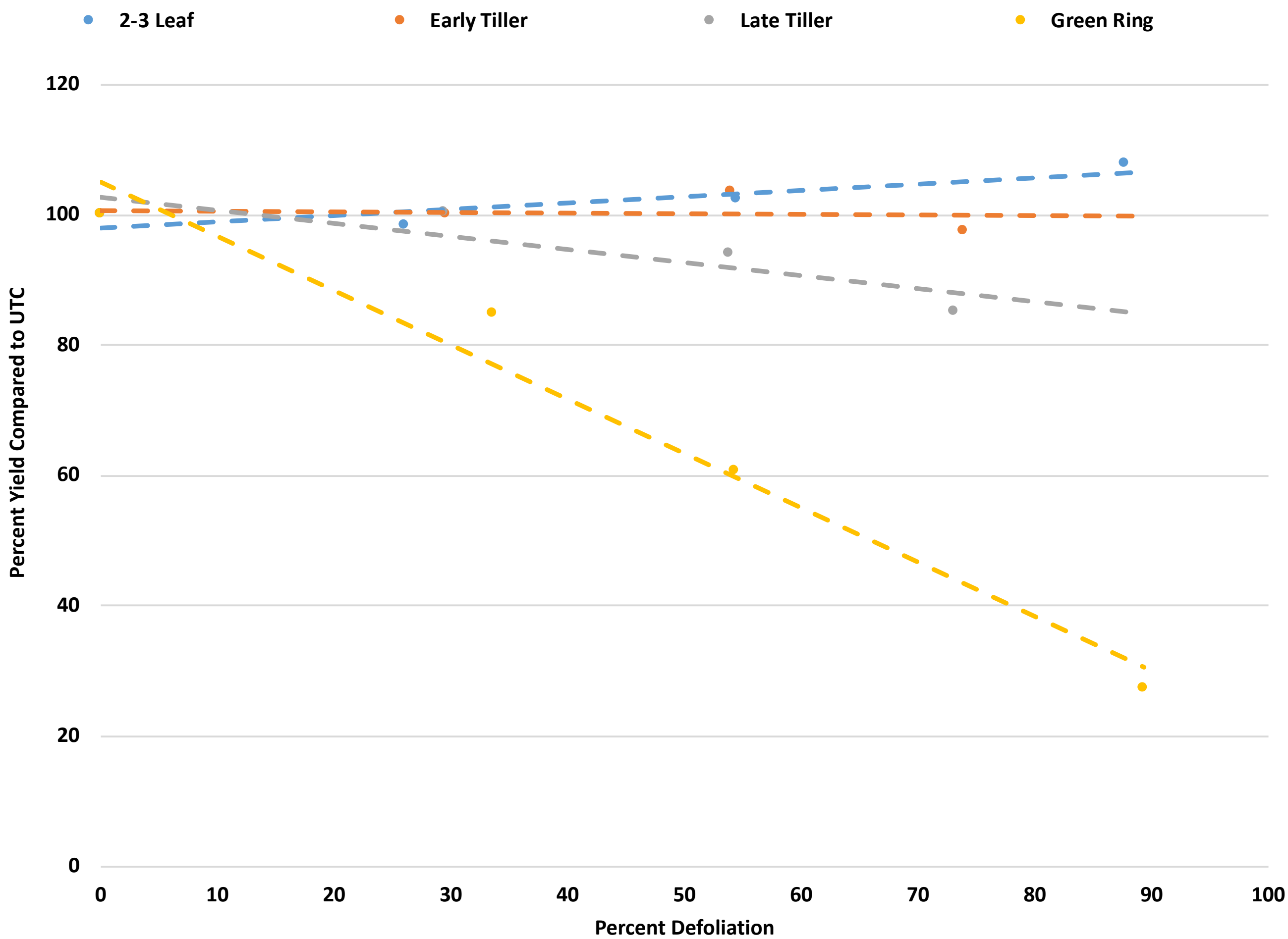

Fig. 2. Yield impacts caused by varying levels of defoliation for studies conducted in 2019 and 2020 at multiple growth stages for May-planted rice, at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Arkansas. UTC = untreated control.

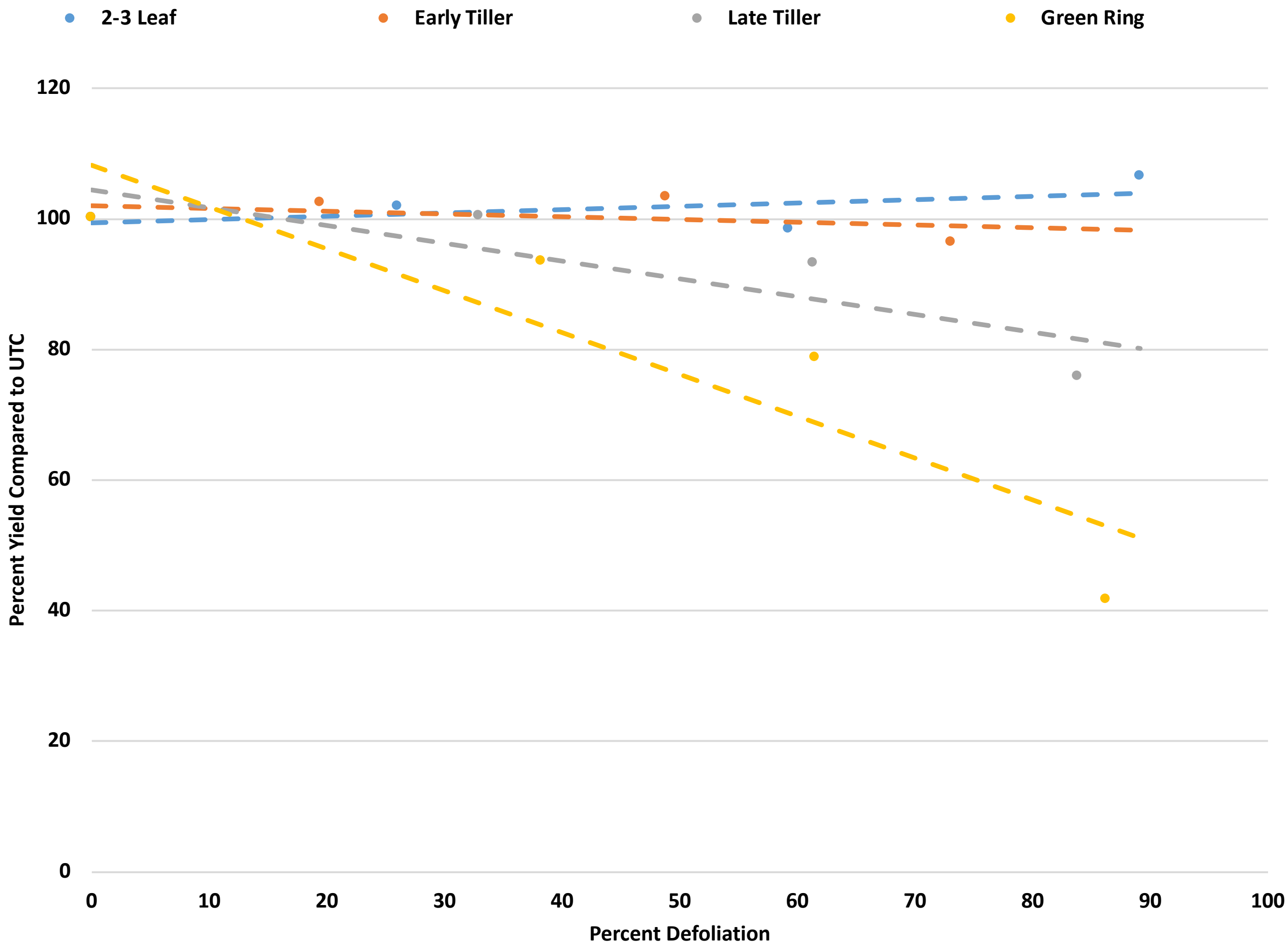

Fig. 3. Yield impacts caused by varying levels of defoliation for studies conducted in 2019 and 2020 at multiple growth stages for June-planted rice, at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Arkansas. UTC = untreated control.

Table 1. Days in delayed heading in rice caused by defoliation at multiple growth stages for studies conducted in 2019 and 2020 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Arkansas.

		Planting Date					
		April		May		June	
Growth Stage	**% Defoliation**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
2-3 leaf	0	0.0 (0.0) i†	0.0 (0.0) e	0.0 (0.0) i	0.0 (0.0) c	0.0 (0.0) j	0.0 (0.0) f
	33	0.0 (0.0) i	0.0 (0.0) e	0.0 (0.0) i	0.0 (0.0) c	0.0 (0.0) j	0.3 (0.5) f
	66	0.0 (0.0) i	0.0 (0.0) e	0.0 (0.0) i	0.0 (0.0) c	0.0 (0.0) j	0.8 (0.9) def
	100	0.5 (0.2) hi	6.2 (2.0) b	1.7 (0.3) h	0.0 (0.0) c	1.3 (0.2) i	3.2 (3.5) cd
Early Tiller	0	0.0 (0.0) i	0.0 (0.0) e	0.0 (0.0) i	0.0 (0.0) c	0.0 (0.0) j	0.0 (0.0) f
	33	0.8 (0.2) hi	0.0 (0.0) e	1.8 (0.3) h	0.0 (0.0) c	2.2 (0.3) hi	0.0 (0.0) f
	66	1.5 (0.2) gh	0.3 (0.8) e	2.5 (0.2) h	0.0 (0.0) c	3.2 (0.3) h	0.7 (1.0) f
	100	2.3 (0.2) g	1.7 (0.8) de	4.5 (0.4) g	1.2 (2.9) c	5.5 (0.4) g	4.0 (1.3) c
Late Tiller	0	0.0 (0.0) i	0.0 (0.0) e	0.0 (0.0) i	0.0 (0.0) c	0.0 (0.0) j	0.0 f
	33	3.7 (0.5) f	0.0 (0.0) e	6.5 (0.4) f	0.0 (0.0) c	7.8 (0.6) f	2.8 (2.4) cd
	66	5.0 (0.4) e	1.8 (2.7) de	8.0 (0.6) e	1.2 (2.9) c	10.2 (0.6) e	7.5 (1.2) b
	100	7.7 (0.3) d	8.7 (3.3) a	11.5 (0.4) d	6.0 (2.6) ab	13.5 (0.6) d	8.2 (2.1) b
Green Ring	0	0.0 (0.0) i	0.0 (0.0) e	0.0 (0.0) i	0.0 (0.0) c	0.0 (0.0) j	0.0 (0.0) f
	33	9.0 (0.5) c	0.0 (0.0) e	13.7 (0.3) c	0.0 (0.0) c	16.3 (0.5) c	2.0 (2.4) cdef
	66	11.8 (0.6) b	3.2 (4.3) cd	18.3 (0.6) b	4.8 (4.5) b	23.2 (0.5) b	8.8 (3.3) b
	100	15.2 (0.7) a	5.3 (2.6) bc	24.5 (0.8) a	7.0 (0.5) a	29.8 (0.7) a	12 (3.5) a
***P*-value**		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

†Means followed by the same letter are not significantly different at $P = 0.05$.

Evaluation of Insecticide Seed Treatments in Furrow Irrigated Rice for Control of Rice Billbug (*Sphenophorus pertinax*)

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Abstract

Arkansas rice producers have increased furrow irrigated rice (FIR) production acreage to reduce labor, tillage, and make crop rotation easier. The elimination of a flood across the field has made rice more susceptible to rice billbug (*Sphenophorus pertinax*). Rice billbug feed on the roots and tillers of rice plants, causing dead tillers and rice panicles to abort, resulting in direct yield loss. As FIR acreage continues to increase in Arkansas, a cost-effective management strategy for rice billbug is needed. An experiment was conducted in 2020 to evaluate the effectiveness of insecticide seed treatments for the control of rice billbug. Neonicotinoid and diamide insecticide seed treatments, alone and in combination, were included in the study. Multiple sampling methods were tested to correlate rice billbug damage to grain yield. When signs of billbug feeding appeared, rice was sampled by counting total tillers and damaged tillers in five linear feet per plot. After panicle emergence, the number of blank heads per five linear feet within a plot were also recorded. A similar trend in grain yield and damaged tiller counts was observed when comparing treatments, but no correlation was observed between damaged tillers and grain yield. Blank heads did not correlate well with grain yield and showed no differences among treatments. Plots with a seed treatment containing a neonicotinoid in combination with Fortenza, as well as Dermacor in combination with CruiserMaxx, resulted in yields greater than the untreated check or CruiserMaxx alone.

Introduction

FIR acreage has been increasing in Arkansas over the past five years (Hardke and Chlapecka, 2019). In this production system, there is no standing water across the top third of the field, which has altered the pest complex for rice. Rice billbug (*Sphenophorus pertinax*) has commonly been considered a minor insect pest in the traditional flooded rice system, typically only feeding on rice found on the levee. Billbugs are restricted to the levee rice in these fields because they cannot survive in a flooded environment. Because FIR has changed irrigation practices, these fields are now susceptible to rice billbug injury. Prior to 2018, essentially no research had been conducted on rice billbug due to its inability to infest rice planted in the traditional paddy system. Felts et al. (2019) found that combinations of neonicotinoids and diamide seed treatments resulted in higher yields than standalone insecticide seed treatments. Developing best management practices for rice billbug in row rice is imperative as the popularity of this production system continues to increase.

Procedures

An experiment was conducted in 2020 at one FIR location in Jackson County, Arkansas. RiceTec RT7301 conventional long-grain hybrid rice was planted on 4 April. All rice was treated with a base fungicide package consisting of sexdaxane, mefenoxam, azoxystrobin, and fludioxonil. Plot size was 16 rows on 7.5 in spacing by 16.5 ft. Treatments consisted of single insecticide and combinations of insecticide seed treatments. Treatments were arranged as a randomized complete block with four replications (Table 1). Two sampling methods were evaluated to measure yield losses associated with rice billbug feeding. For the first sampling method, the total number of undamaged and rice billbug damaged tillers was recorded for all plants in 5 linear feet per plot at the green ring growth stage. For the second sampling method, the total number of undamaged panicles and blank panicles were recorded for 5 linear feet per plot at the R9 growth stage. All plots were harvested using a plot combine equipped with a harvest master system. Data was analyzed in PROC GLIMMIX with SAS v 9.4 (SAS Institute, Cary, N.C.) at an alpha level of 0.05.

Results and Discussion

No relationship between tiller damage and grain yield was observed (Fig. 1); however, differences between treatments were observed for damaged tillers. CruiserMaxx + Dermacor and NipsIt + Fortenza had less tiller damage than the untreated, NipsIt + Dermacor, or CruiserMaxx (Fig. 2). A correlation was not observed between grain yield and blank heads, and no differences were observed among treatments for blank panicles (Figs. 3 and 4). Plots treated with CruiserMaxx, or CruiserMaxx + NipsIt did not yield different than the untreated check. Plots treated with NipsIt + Fortenza as well as, CruiserMaxx + Dermacor yielded higher than CruiserMaxx alone or the untreated check (Fig. 5).

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Practical Applications

Preliminary data suggest that combining neonicotinoid and diamide seed treatments provide greater suppression of billbug when compared to single product seed treatments. Treatment combinations containing NipsIt + Fortenza and CruiserMaxx + Dermacor resulted in less tiller damage and greater grain yields than untreated plots or rice with CruiserMaxx alone. Damage tiller sampling showed some similarities between treatments when compared to yield. Damage tiller sampling timing needs to be refined because earlier sampling will allow undeveloped damage tillers to be accounted for. No reduction in blank heads was observed for any treatment. This suggests that blank head counts alone do not correlate with grain yield. One possible explanation for the lack of differences is that tillers infested by billbug never developed enough to produce a blank head.

Acknowledgments

We would like to thank Arkansas Rice Promotion Board for funding this research through the Arkansas Rice Checkoff, as well as Stan Haigwood for the use of his land, and Arkansas Cooperative Extension Service county agents for their collaboration with this project. This could explain why yield and blank head do not correlate, whereas similar trends for damage tillers and yield are observed.

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Table 1. Trade names, rates, and insecticide class included in analysis.

Trade Name	Rate (oz/cwt)	Insecticide Class
CruiserMaxx Rice (CMR) (Thiamethoxam)	7	Neonicotinoid
NipsIt Inside (NIP) (Clothianidin)	1.92	Neonicotinoid
Dermacor (DMC) (Chlorantraniliprole)	5	Diamide
Fortenza (FTZ) (Cyantraniliprole)	3.4	Diamide
Regent (FIP) (Fipronil)	8	Phenylpyrazole
CruiserMaxx Rice + NipsIt Inside (CMR + NIP)	7 + 1.92	Neonicotinoid + Neonicotinoid
CruiserMaxx Rice + Dermacor (CMR +DMC)	7 + 5	Neonicotinoid + Diamide
CruiserMaxx Rice + Fortenza (CMR + FTZ)	7 + 3.47	Neonicotinoid + Diamide
NipsIt Inside + Dermacor X-100 (NIP+DMC)	1.92 + 5	Neonicotinoid + Diamide
NipsIt Inside + Fortenza (NIP + FTZ)	1.92 + 3.47	Neonicotinoid + Diamide
Untreated	N/A	N/A

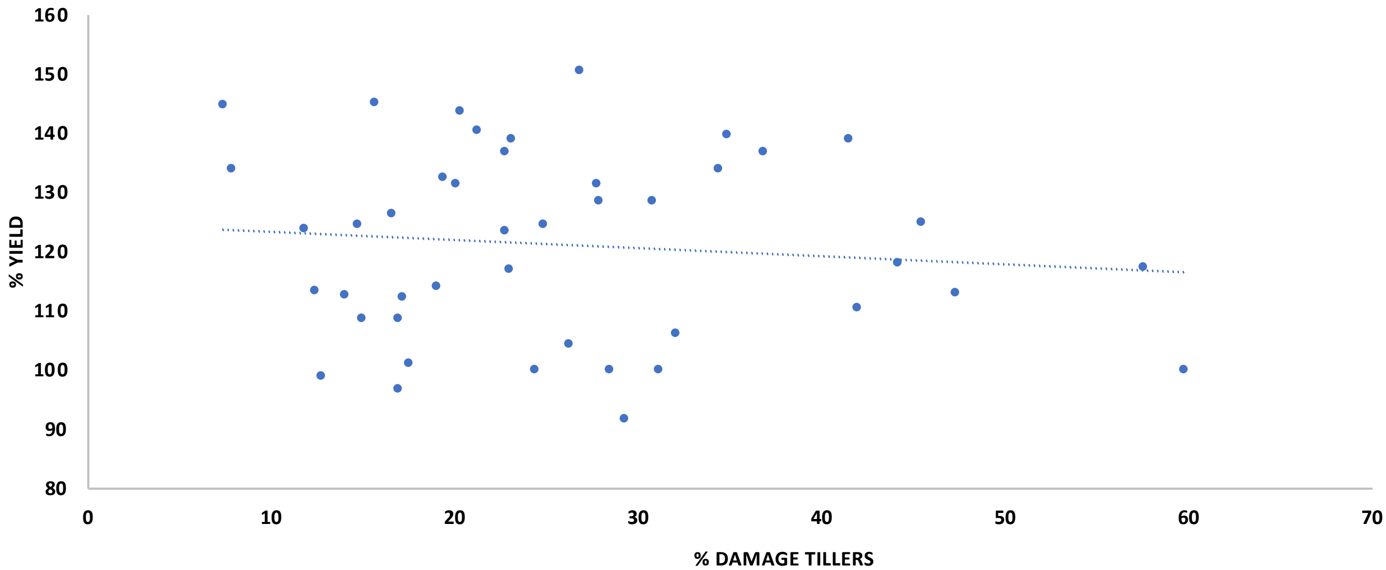

Fig. 1. Comparing the relationship between grain yield and % tiller damage caused by rice billbug feeding from furrow irrigated rice plots. Y = -0.137x + 124.74, *P* = 0.89.

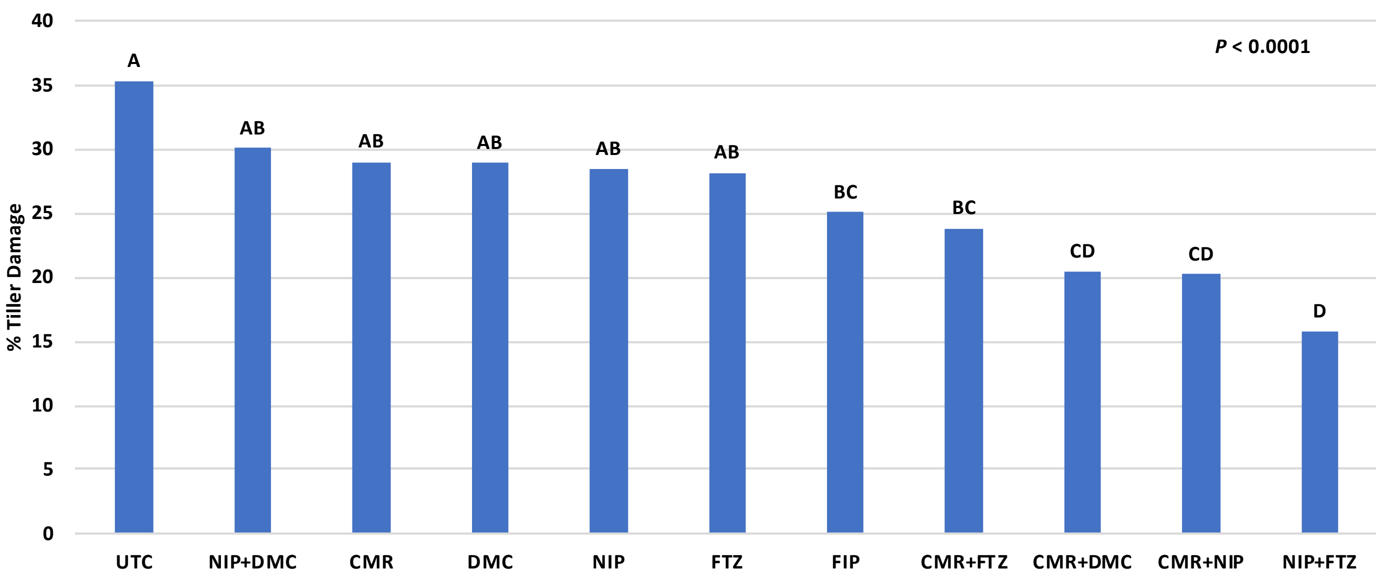

Fig. 2. Percent damaged tillers caused by rice billbug in furrow irrigated rice for selected insecticide seed treatments. UTC = untreated check; NIP = NipsIt; DMC = Dermacor; CMR = CruiserMaxx; FTZ = Fortenza; FIP = Fipronil.

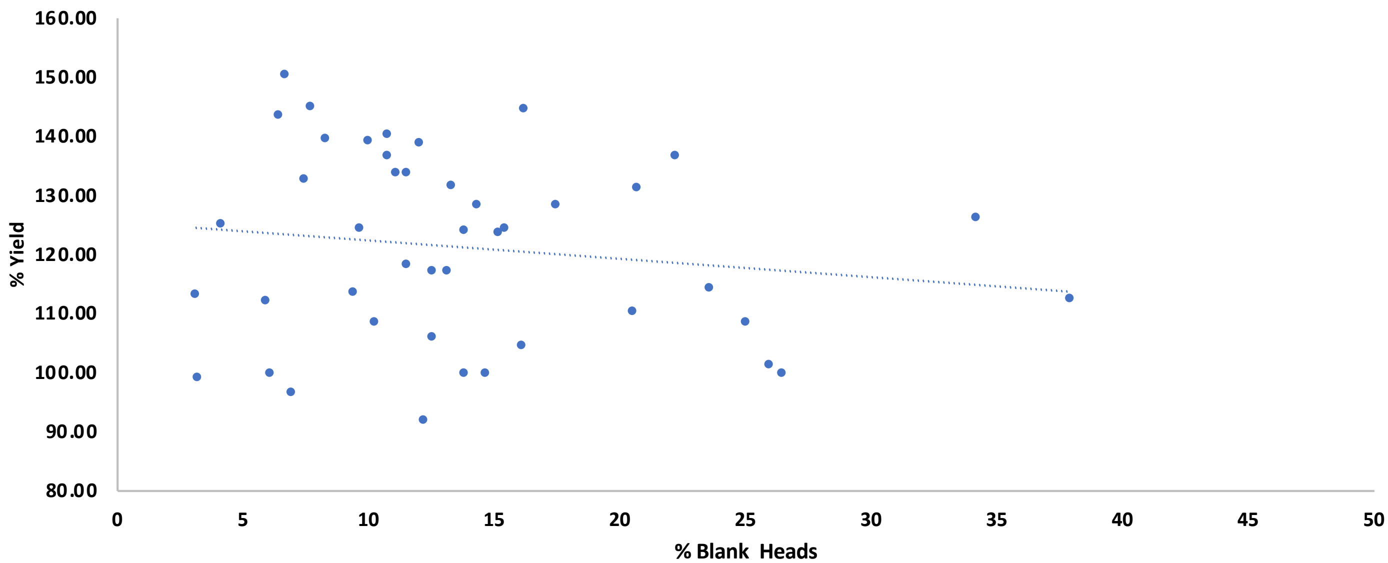

Fig. 3. Comparing the relationship of grain yield and % blank heads caused by rice billbug in furrow irrigated rice. Y = -0.3108x + 125.5, *P* = 0.33.

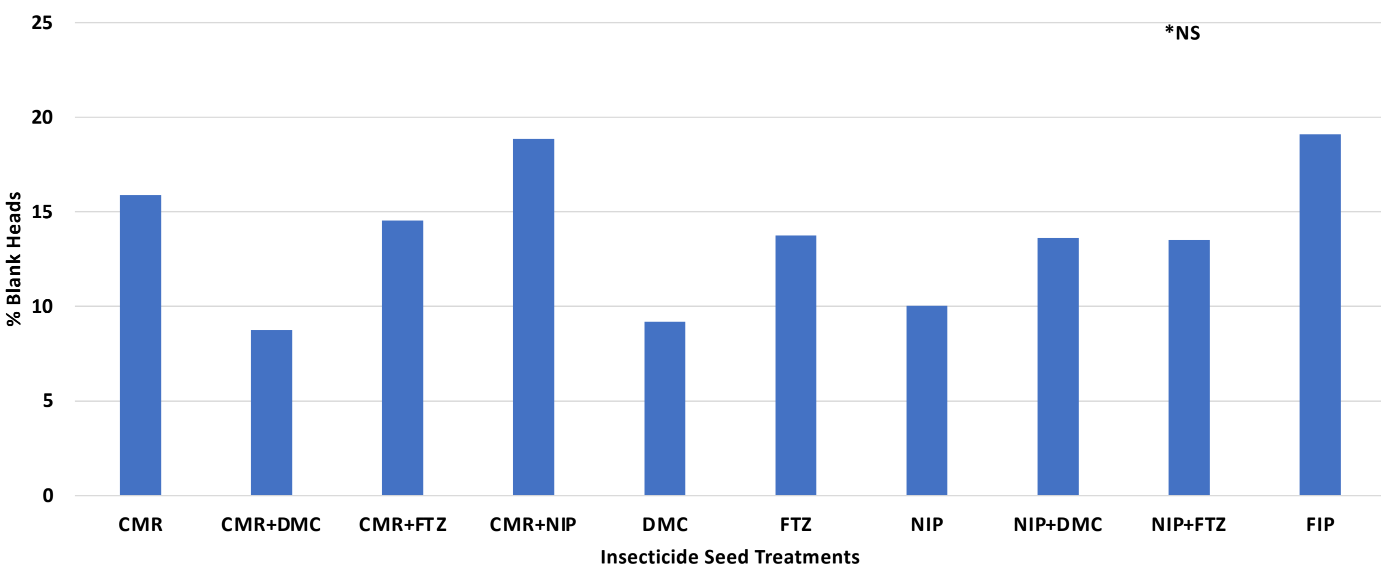

Fig. 4. Blank panicles caused by rice billbug feeding for selected insecticide seed treatments in furrow irrigated rice. CMR = CruiserMaxx; DMC = Dermacor; FTZ = Fortenza; NIP = NipsIt; FIP = Fipronil.

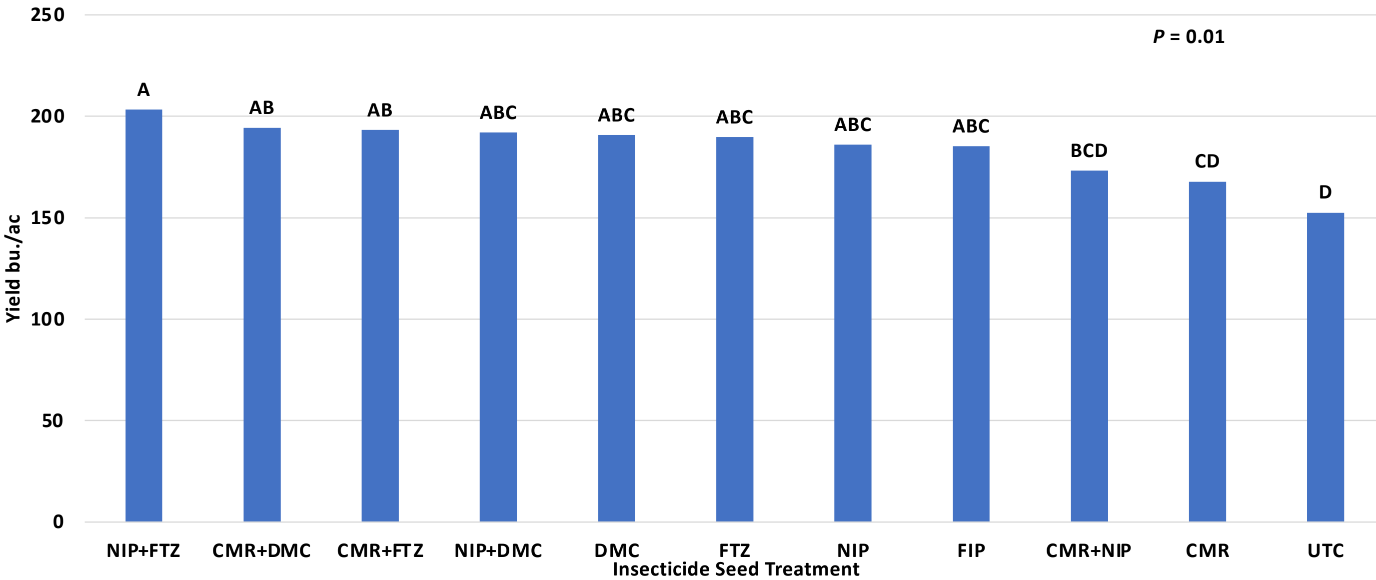

Fig. 5. Rice grain yield of selected insecticide seed treatments for control of rice billbug in furrow irrigated rice. NIP = NipsIt; CMR = CruiserMaxx; DMC = Dermacor; FTZ = Fortenza; FIP = Fipronil; UTC = untreated check.

Evaluating the Distribution and Monitoring Systems for Rice Billbug (*Sphenophorus pertinax*) in Furrow Irrigated Rice

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Abstract

Furrow irrigated rice (FIR) production acreage is increasing in Arkansas due to potential cost savings on tillage and levee construction when compared to flood irrigated rice. In a FIR system, there is a lack of standing water across the top portion of the field, which increases the field's susceptibility to rice billbug (*Sphenophorus pertinax*). Rice billbugs feed on the roots and tillers of rice plants, causing rice seed heads to abort and yield loss to occur. As FIR production systems increase across Arkansas, so has the demand for rice billbug monitoring strategies. A survey was conducted across four states in 65 FIR fields to monitor billbug distribution. Studies were also conducted in three FIR fields in Arkansas to evaluate trapping and monitoring methods for rice billbugs using multiple insect trap styles.

Introduction

In the Mid-southern U.S., Arkansas, Louisiana, Missouri, and Mississippi are prominent rice-growing states, responsible for 77% of total rice harvested nationally in 2020 (USDA-NASS, 2020). Furrow irrigated rice (FIR) production has increased in recent years as rice producers seek reduced labor and more efficient rice production practices. This system has the potential to reduce fuel costs due to reduced tillage and levee construction. Moving to a furrow irrigated production system has altered the field environment allowing it to be more favorable to non-typical rice pests. Rice billbug is considered a minor rice pest in the traditional flooded system, typically only found feeding on rice planted on the levees. Without the presence of a flood and increased plant density for cover, FIR has become a favorable host for billbugs (Dupuy and Ramirez, 2016). Very little research has been conducted on rice billbug biology and monitoring, and fundamental research is needed to understand the impact and yield loss associated with rice billbug in a FIR system. The objective of this study is to determine rice billbug distribution in the Mid-southern U.S. and analyze different trapping methods to create a successful monitoring program.

Procedures

Monitoring Systems for Rice Billbug

An experiment was conducted at one FIR location in Jackson County during the 2019 and 2020 growing seasons. RiceTec RT CLXL745 hybrid in 2019 and RiceTec RT7301 in 2020 were selected for their high rice blast resistance and were planted at a rate of 22 lb/ac. Eight styles of traps were evaluated to determine the best method for monitoring rice billbug entering the field, these included: colored five-gallon buckets, pitfall traps, several ground cover methods, flight interception traps, light traps, sticky cards, and pyramid traps. Each trap was checked weekly starting the first week in May for sixteen consecutive weeks.

Bucket. A series of six five-gallon buckets were placed on the rice field edge separating the possible overwintering site from the production field. Six colors, pink, green, blue, orange, yellow, and gray, were placed in random order along the field edge and were replicated four times at each location. Buckets were moved laterally each week to allow fresh grass to remain under the buckets. Each bucket was checked weekly, and specimens were collected from the grass under each bucket.

Pitfall Trap. Four linear pitfall traps were buried in the plant bed closest to the field edge, with the top of the trap level with the soil surface. Pitfalls were made from 4-in. PVC pipe that was 4 ft in length and with a 1.5-in. slit cut in the top and capped at one end. The other end was equipped with a plastic collection container. Linear pitfalls were buried at a slight angle where the lowest point of the grade leads to the collection container. Insects that fall into the trap are forced to travel into the collection container.

Ground Cover Methods. A series of different materials were placed along the field edge and monitored weekly to determine if the billbug adults would seek cover under the materials. An 8 ft × 8 ft tarp was spread tightly and staked into the ground on top of the soil surface of the turn row. Multiple pieces of plywood, in 3 ft × 3 ft sections, were placed on turn rows as well as 4-ft segments of 4-in. PVC pipe sections that were painted pink.

Flight Interception Trap. Additionally, two flight interception traps were constructed and placed in each experiment location to account for billbug using flight to enter the field. Reports of species similar to rice billbug have been observed as weak fliers. Flight interception traps were designed to force heavier insects

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to compromise their trajectory and force them downward into the collection trough. A screen approximately 7.5 ft in height and 3.5 ft in width was placed in between assumed overwintering sites and production fields. Each trap was equipped with a collection trough placed on each side of the screen, containing a non-toxic pink propylene glycol solution.

Light Trap. Another trap implemented was a universal light trap containing a halo fluorescent black light. Bulbs were controlled by photoelectric sensors that respond to changes in sunlight. Photoelectric sensors were connected to a deep cycle marine battery, which provided efficient power between collections. Batteries were replaced and recharged weekly throughout the experiment. The bucket was modified with an aluminum funnel to collect specimens within the bucket. Two light traps were placed at each location.

Sticky Cards. Four replications of sticky cards were placed on a wooden post at 3 ft and 7 ft from the soil surface and were distributed evenly throughout the top two-thirds of the field. Yellow 6 in. × 12 in. and orange 9 in. × 15 in. sticky cards were placed on alternating posts. Sticky cards received additional applications of insect collection adhesive. Sticky cards were replaced weekly.

Pyramid Traps. Two black pyramid insect traps were placed along the field edge. The traps were made of black corrugated plastic triangles standing 4 ft in height and staked into the soil. The pyramid trap design is intended to lure insects upward once they land on the trap. A plastic collection jar at the top of the trap encloses insects inside until collection counts can be taken.

All data were analyzed with an analysis of variance in PROC GLIMMIX SAS v 9.4 (SAS Institute, Inc., Cary N.C.).

Billbug Survey

A survey was conducted on 65 FIR fields across the 2019 and 2020 growing seasons in 4 states across Arkansas (49), Missouri (8), Louisiana (6), and Mississippi (2). Observations were taken of the surrounding landscape in the four cardinal directions around each field. At each location, three pink five-gallon buckets were distributed equally throughout the top two-thirds of the field, where billbug damage has been commonly found. Every week throughout the growing season, buckets were checked for adults, and fields were scouted for billbug larvae and damage. Once billbug damage was identified in the field, growth stage was collected to predict billbug migration into the field.

Results and Discussion

Billbug Monitoring

Bucket Color Preference. Data from 2019 and 2020 suggests buckets that were colored pink had consistently greater numbers of billbug gathered under them than other color variations. No differences were observed among the other colors (Fig. 1). These data suggest pink is a preferred color by rice billbug, and rice billbug traps should implement the color.

Trap Style. Bucket traps and collection troughs generated the greatest percent of billbug specimens collected (Table 1). Traps designed for ground active insects collected 99% of the total for both years. Collections made under the collection troughs of the flight interception traps dramatically increased when the pink propylene glycol solution was used. This observation agrees with findings that were made in the color preference experiment for rice billbug. No billbugs were ever found inside the light trap but were rather found underneath the collection bucket. These data suggest collections made with traps designed for ground-active insects are better for monitoring billbugs than those designed for more flight-prone insects. These findings suggest that rice billbugs are likely crawling to infest rice fields rather than flying.

Billbug Survey

Rice billbug damage was observed at survey locations in both Arkansas and Missouri. Billbug damage was not found at any locations in Louisiana or Mississippi, though damage has been reported in these regions. Across the 53 survey locations during 2019, rice billbug damage and larvae were observed at 60% of fields. In Arkansas, 29 of 37 fields surveyed had a presence of rice billbug within the field in 2019, and 12 out of 15 fields were infested in 2020. In Missouri, 50% of fields surveyed had a billbug infestation. Data pooled from both growing seasons show that of the fields that were infested with billbug, 80% had grassy borders. In contrast, of the sampled fields that were not bordering a grassy area, only 7.7% had an infestation of rice billbug. Plant vegetation surrounding FIR fields also influenced the risk of billbug infestation. FIR fields where tree lines were surrounding at least one side of the field showed the highest risk of infestation (62%). Fields where solely natural grasses or grassy turn rows were present, along with fields only surrounded by row crop production, had a reduced risk of infestation of 24% and 22%, respectively. These preliminary data suggest that billbug infestation is more likely in fields with at least one surrounding tree line, where early season food resources such as Bermuda grass (*Cynodon dactylon*) and sedges (Family:Cyperaceae) are available.

Observations suggest billbug migrations into FIR predominantly occurred prior to the 3-4 tiller growth stage. Observational greenhouse data shows damage affiliated with adult billbug feeding begins to show symptomology 5-7 days after initial feeding occurs. Data from both growing seasons suggested that initial symptoms from billbug feeding occur at the 3-4 tiller growth stage (58%). Infestation occurrences were not as common during 5-6 tiller (25%), green ring (8.5%), or boot (8.5%) growth stages

Based on 2019 and 2020 trapping data, increasing billbug densities are observed the last week in May, with a peak occurring during the first week in June. A second peak in billbug densities was observed the 3rd week in July, but collection numbers were not as prominent as the initial peak. Based on overwintering monitoring of billbugs, they can overwinter as adult, larvae, or pupae. A second migration to the field may suggest that early instar overwintering larvae that survive have cycled through development and are migrating to the field.

Practical Applications

Billbugs were prone to crawl under the base of all the tested trapping systems and remain on the soil surface while being hidden. The pink-colored buckets were more attractive than all other tested colors. Currently, research is being conducted to extract sex pheromones from rice billbugs in hopes of improving monitoring techniques. Together, these experiments have the potential to create a successful monitoring technique to develop a management strategy for rice billbug. This research will eventually aid Arkansas rice growers by detecting the presence of rice billbug and employing timely management strategies in order to preserve yield

Acknowledgments

We would like to thank Arkansas Rice Promotion Board for funding this research through the Arkansas Rice Checkoff, as well as Stan Haigwood, Parmer Hankins, and RiceTec, Inc. for the use of their land, and Arkansas Cooperative Extension Service county agents for their help with this project.

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Table 1. Weekly percentages of rice billbug collections using various style traps.

	Trapping System								
Date	Bucket[a]	Pitfall[a]	Tarp[a]	Trough[a,c]	Flight Interception[b]	Light[b]	Sticky Cards[b]	Pyramid[b]	Ground Cover[a]
	(% of Weekly Collection Total)								
WK 1[d]	0	0	0	0	0	100[c]	0	0	0
WK 2	56	38	0	6	0	0	0	0	0
WK 3	83	0	6	11	0	0	0	0	0
WK 4	42	7	3	45	0	3	0	0	0
WK 5	67	6	0	27	0	0	0	0	0
WK 6	54	0	0	46	0	0	0	0	0
WK 7	13	0	0	87	0	0	0	0	0
WK 8	43	0	0	57	0	0	0	0	0
WK 9	22	0	33	33	0	0	0	0	12
WK 10	70	0	0	30	0	0	0	0	0
WK 11	26	43	0	31	0	0	0	0	0
WK 12	29	0	0	57	0	0	0	0	14
WK 13	13	63	0	25	0	0	0	0	0
WK 14	25	0	0	50	0	0	0	0	25
WK 15	0	0	0	0	0	0	0	0	0
WK 16	34	0	0	66	0	0	0	0	0
WK 17	0	0	0	0	0	0	0	0	0
WK 18[e]	50	0	0	50	0	0	0	0	0
%Total	49%	12%	2%	34%	0%	1%	0%	0%	2%

[a] Traps designed for ground active insects.
[b] Traps designed for flight active insects.
[c] Billbug collected under trap, not by designed method.
[d] Collection date started first week in May.
[e] Collection date ended last week in August.

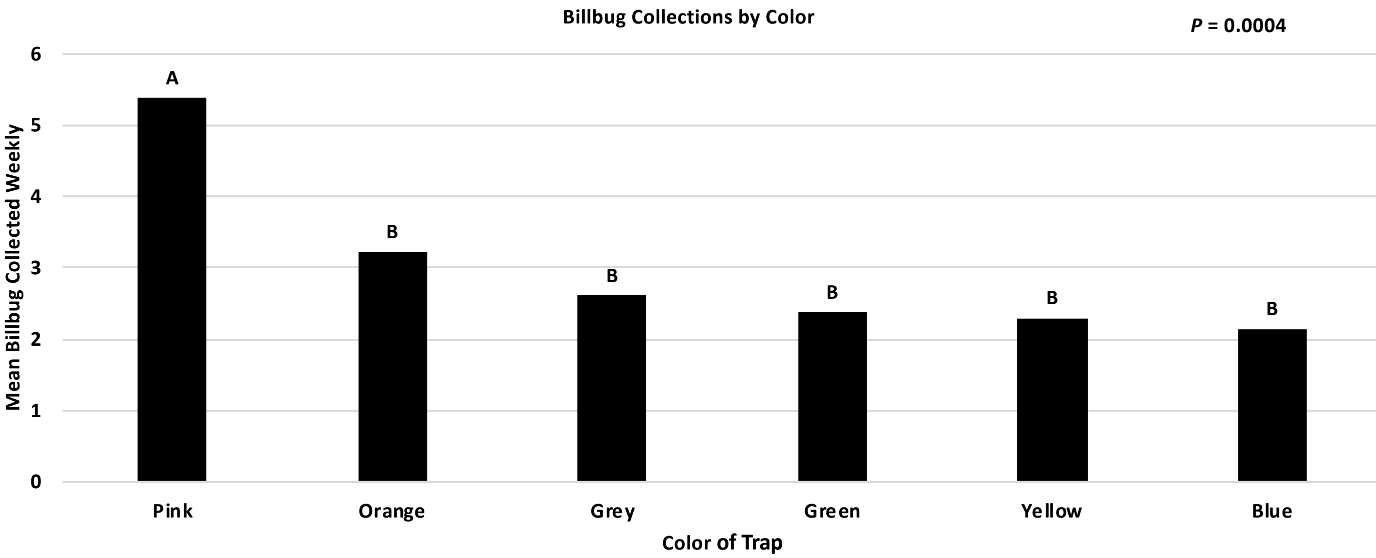

Fig. 1. Collection of rice billbug using different color traps. Treatments with the same letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

Efficacy of Selected Insecticides for Control of Rice Stink Bug, *Oebalus pugnax*, in Arkansas, 2020

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Abstract

In the last three years, over 50% of the rice acreage in Arkansas received an insecticide application for rice stink bug. Because of the significance of this pest in rice production, we continually monitor currently recommended insecticides as well as new insecticides to make the most efficient and economic recommendations for rice producers. Recent research indicates that lambda-cyhalothrin, which is the most frequently used insecticide for control of rice stink bug, may be showing reduced efficacy due to insecticide resistance. A study was conducted to evaluate the efficacy of the most common insecticides used for rice stink bug control and to compare them with a new insecticide not registered for use that may provide better long-lasting control.

Introduction

The rice stink bug, *Oebalus pugnax*, is considered a major pest of rice. In the past 3 seasons, over 50% of rice fields in Arkansas received an insecticide application for control of this pest. During the early stages of grain development, the piercing-sucking stylet of the rice stink bug penetrates the rice hull and removes the grains' content resulting in yield loss. In the later stages of grain development, feeding causes discoloration of the kernel, which is called 'pecky' rice (Swanson and Newsom, 1962).

Rice stink bugs usually move to rice from weeds or other rotational commodities during heading (Way, 2003). Some of the alternate hosts for rice stink bug include grain sorghum, oats, rye, wheat, barnyardgrass, bearded sprangletop, dallisgrass, lovegrass, ryegrass, crabgrass, broadleaf signalgrass, and several species of *Panicum* (Lorenz et al., 2018). Tindall et al. (2005) observed an increase in pecky rice with the presence of these weeds in and around fields and an increase in unfilled kernels due to higher densities of rice stink bug.

The threshold for stink bugs in Arkansas, during the first two weeks of heading, is five rice stink bugs per 10 sweeps with a standard 15-inch sweep net. During the next two weeks, the threshold increases to 10 rice stink bugs per 10 sweeps. In these cases, the use of an insecticide is recommended (Lorenz et al., 2018). On average, one application is adequate for the control of rice stink bug. In years with high populations, particularly for rice heading very early or very late, multiple applications may be warranted to reduce populations lower than the action threshold (Lorenz et al., 2018).

While pyrethroids, the predominant insecticide class used for control of rice stink bug, provides adequate protection for 5 to 7 days, an insecticide that would provide longer-lasting control would be advantageous for growers. The purpose of this study was to evaluate the efficacy and residual control of selected insecticides for rice stink bug.

Procedures

A trial was conducted in Stuttgart, Arkansas, on a grower field. Plot size was 15 ft by 35 ft in a randomized complete block design with four replications. Foliar treatments included: LambdaCy 2EC (3.65 oz/ac); Mustang Maxx (4 oz/ac); Tenchu (8 oz wt/ac); Carbaryl 4F (32 oz/ac); Malathion 4E (32 oz/ac); and, two rates of Endigo ZCX (5 and 6 oz/ac). LambdaCy and Mustang Maxx are pyrethroids, and Tenchu (dinotefuran) is a neonicotinoid. Carbaryl is a carbamate, and Malathion is an organophosphate. Endigo ZCX is a premix of thiamethoxam (1.8 lb ai) and lambda-cyhalothrin (0.9 lb ai). All treatments were compared to an untreated check (UTC). Insecticide treatments were applied with a hand boom on 21 August. The boom was fitted with TX6 hollow cone nozzles at 19-in. nozzle spacing; spray volume was 10 gal/ac, at 40 psi. Insect counts were taken at 3, 6, 10, and 13 days following treatment by taking 10 sweeps per plot with a standard sweep net (15-in. diameter). Data were processed using Agriculture Research Manager v. 9, analysis of variance, and Duncan's New Multiple Range Test ($P = 0.10$) to separate means.

Results and Discussion

At 3 days after application (21 August), all treatments reduced rice stink bug adults and nymphs compared to the untreated check. The untreated had just over 10 rice stink bugs per 10 sweeps,

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around 2X threshold of 5 rice stink bugs per 10 sweeps. None of the treatments were different (Fig. 1). At 6 days after application, there was a similar trend with stink bugs in the untreated climbing to 3X threshold with no differences observed between the treatments, although all treatments reduced numbers below the threshold (Fig. 2). At 10 days after application, the untreated check had increased to 21 stink bugs per 10 sweeps; at this time all treatments exceeded the threshold of 5 stink bugs per 10 sweeps. Malathion had significantly more stink bugs than Tenchu and Carbaryl (Fig. 3). A similar trend was observed at 13 days post application. All treatments, with the exception of Malathion, had fewer stink bugs compared to the untreated check (Fig. 4). In a grower field, a second application would have been required for all treatments at 10 days; although, at 13 days, Tenchu and Carbaryl were below the threshold of 5 per 10 sweeps but were not different than the lambda-cyhalothrin or either Endigo ZCX rate.

Practical Applications

Rice producers have limited options for control of rice stink bug and none with long-term residual control. In most cases, only one application is needed for control of rice stink bug, but for very early and very late-planted rice, this may not be the case. For these acres, a product with long residual control is needed. Currently, there are no labeled products for rice stink bug that can consistently provide the control needed for rice stink bug past 7–14 days, as shown in our trials the last several years. While there are concerns for resistance to lambda-cyhalothrin, this study would indicate that it is still performing well enough for growers to continue using the product. We will continue to monitor currently labeled insecticides and any other insecticides which may help control stink bugs in rice.

Acknowledgments

The authors would like to express our appreciation for funding and support from the Arkansas rice growers administered through the Rice Research and Promotion Board. Support is also given by the University of Arkansas System Division of Agriculture. We would also like to thank Mathew Feilke and Feilke Farms for the use of their land.

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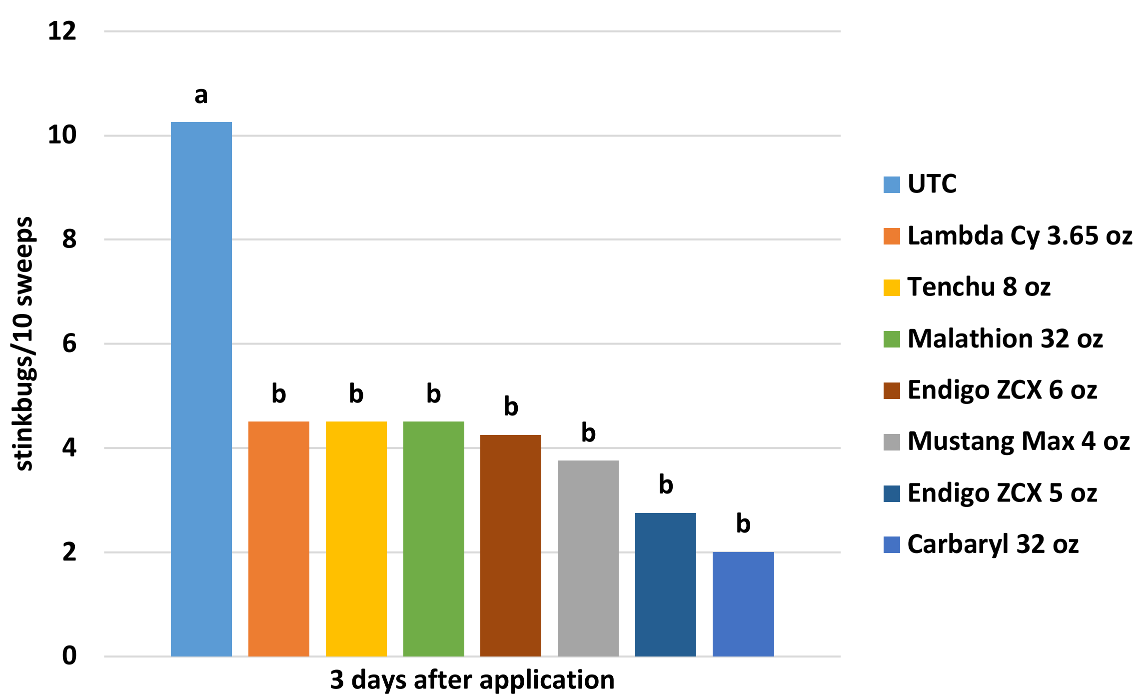

Fig. 1. Efficacy of selected insecticides at 3 days after application for control of rice stink bug. Means followed by the same letter are not significantly different. UTC = untreated check.

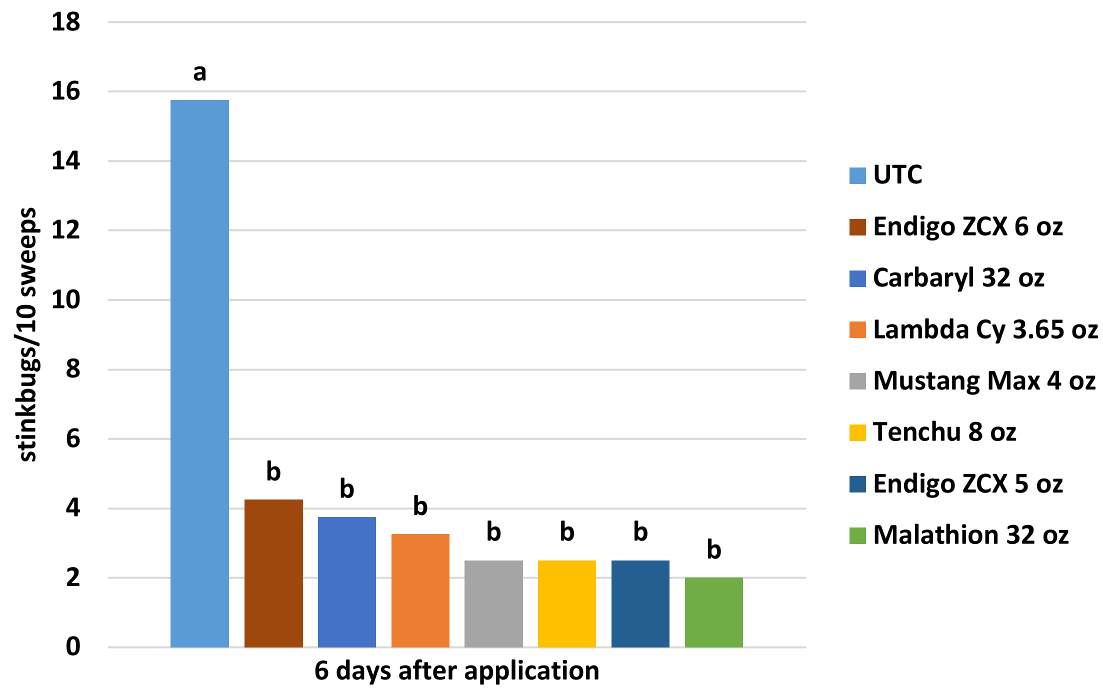

Fig. 2. Efficacy of selected insecticides at 6 days after application for control of rice stink bug. Means followed by the same letter are not significantly different. UTC = untreated check.

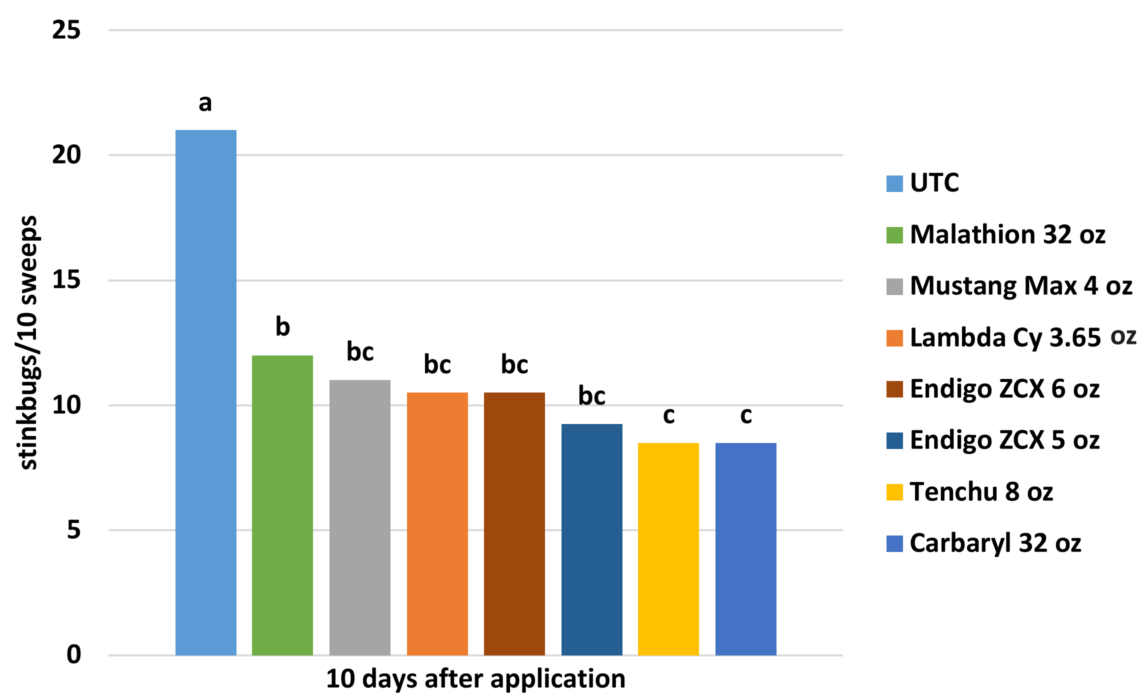

Fig. 3. Efficacy of selected insecticides at 10 days after application for control of rice stink bug. Means followed by the same letter are not significantly different. UTC = untreated check.

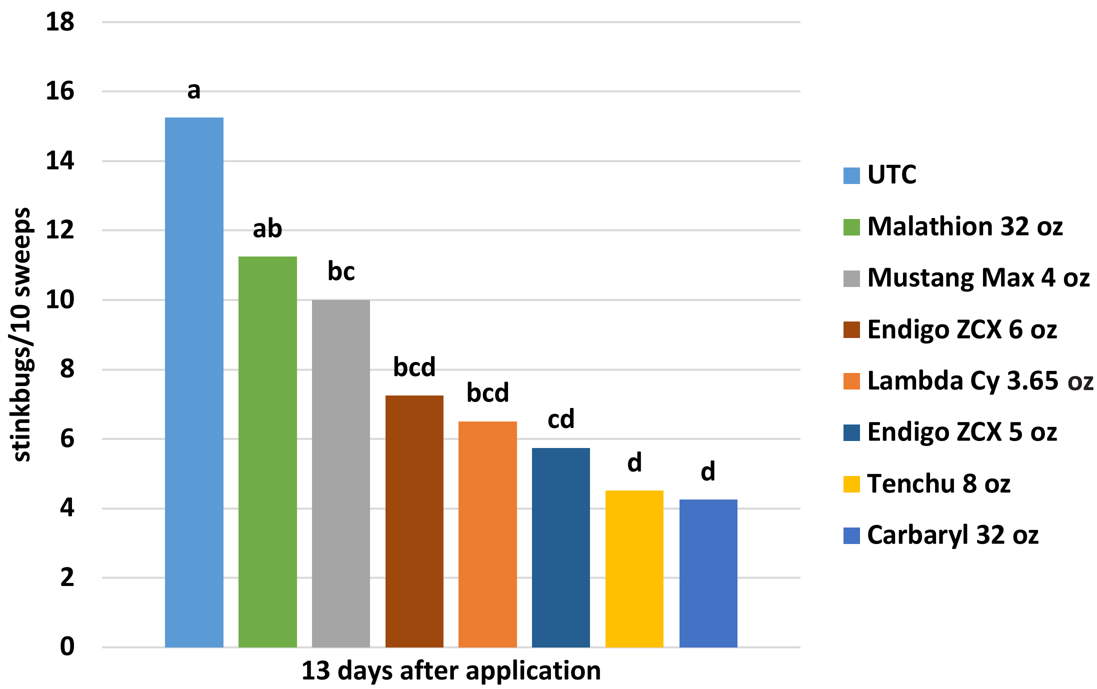

Fig. 4. Efficacy of selected insecticides at 13 days after application for control of rice stink bug. Means followed by the same letter are not significantly different. UTC = untreated check.

Large Block Comparisons of Dinotefuran and Lambda-Cyhalothrin for Control of Rice Stink Bug

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Abstract

Rice stink bug (*Oebalus pugnax*) is a major pest of rice, feeding on developing grain, which can lead to yield and quality losses. Few insecticides are currently available to rice producers for rice stink bug management, and those that are labeled lack residual control. Lambda-cyhalothrin (lambda) has been the most used insecticide for the control of rice stink bug due to it being highly efficacious and cost-effective for growers. Other chemical options, such as dinotefuran (Tenchu), are effective for controlling rice stink bug but are cost-prohibitive for growers. This raises concern for the longevity of products such as lambda, and resistance monitoring is needed. New control options for rice stink bug need to be evaluated if resistance to lambda is documented in the mid-South. Large block experiments were conducted at three locations in 2020 to compare lambda and Tenchu for efficacy and residual control of rice stink bug. Sweep net sampling was performed pre-application and every 2–3 days post-application for two weeks to monitor stink bug populations. No differences were observed between products at any location regarding efficacy and residual.

Introduction

Rice stink bug (RSB), *Oebalus pugnax* (F.), is a major pest of rice in Arkansas. The RSB can cause yield loss if feeding occurs during the flowering and milk growth stages or quality loss if feeding occurs during the soft or hard dough growth stages (Swanson and Newsom, 1962). Growers in Arkansas average one application per year for RSB; but in very early or very late heading rice, multiple applications may be warranted to keep RSB densities below the threshold. Limited insecticide options are currently available for RSB control (Lorenz et al., 2018). Lambda-cyhalothrin (Warrior II and generics), a pyrethroid, is the current standard for RSB control due to it being highly efficacious and its economical price of ~$2/ac. However, these products provide little to no residual control for RSB. Growers do have another option in dinotefuran (Tenchu), but it is considerably more expensive than lambda at $12/ac. The objective of this study was to compare the efficacy and residual control of lambda and Tenchu for control of RSB.

Procedures

Large block comparisons of lambda and Tenchu were conducted at three locations, Arkansas County, Faulkner County, and Crittenden County, in 2020. One field in each county was split, with lambda applied to one-half and Tenchu to the other half. Fields were selected that were at or exceeding the RSB threshold. For weeks 1 and 2 after 75% heading, our threshold is 5 RSB per 10 sweeps. For weeks 3 and 4 after 75% heading, our threshold is 10 RSB per 10 sweeps. Plot size was a minimum of 25 acres for both products. Applications were made using an airplane at 3 gal/ac. Warrior II was used to represent lambda at 1.8 oz/ac, and Tenchu was applied at 8.0 oz/ac, with crop oil concentrate at 0.5% v/v added to both products. Rice stink bug densities were estimated using a sweep net at 3, 7, 10, 14, and 17 days after treatment (DAT) by conducting 10 sets of 10 sweeps per plot. Sweep net samples were taken throughout the application area. If either or both treated blocks exceeded the threshold after the initial application, it was retreated. Sampling was conducted until each plot reached 60% hard dough.

Results and Discussion

Arkansas County

Rice stink bug populations were 2x threshold prior to insecticide application. Lambda had greater mean RSB densities at each sample date; however, both products kept the RSB densities below threshold out to 17 DAT (Fig. 1).

Faulkner County

Prior to application, RSB densities were ~2x threshold. Mean RSB densities were greater in the lambda treatment at every sampling date, but both treatments kept RSB densities below threshold out to 14 DAT (Fig. 2).

Crittenden County

Rice stink bug densities were slightly above the threshold before insecticide applications were made. After application, mean RSB densities were greater in the lambda treatment at every sampling date but below threshold out to 10 DAT (Fig. 3).

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Lambda and Tenchu both provided adequate control of RSB at all locations and all sampling dates. Tenchu showed slightly lower mean RSB densities at every sampling date when compared to lambda. However, both products were able to keep RSB densities under the threshold at all sampling dates.

Practical Applications

Rice producers have limited products in their arsenal for controlling RSB. The most widely used product for controlling RSB is lambda. In these large block studies, we observed no differences in efficacy and residual control between lambda and Tenchu. The primary difference between these products is the difference in pricing of the two. Lambda cost approximately $2/ac, whereas Tenchu is $12/ac. With these prices, growers can spray lambda twice for the cost of a single application of Tenchu when application fees are added in. Growers can save more money and achieve the same level of control for RSB with the usage of lambda over Tenchu.

Acknowledgments

The authors would like to express their appreciation to the Arkansas Rice Checkoff Program administered by the Arkansas Rice Research and Promotion Board, the University of Arkansas System Division of Agriculture, and all the cooperators that allowed the use of their land.

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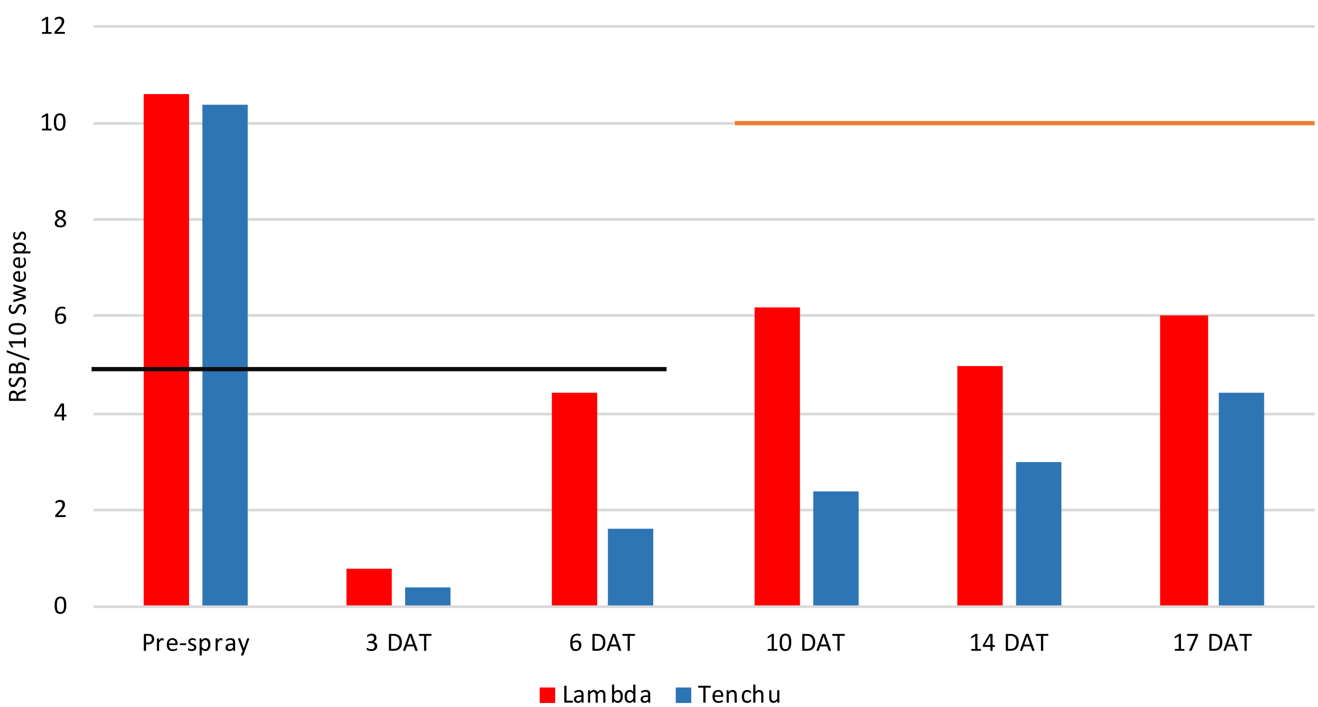

Fig. 1. Large block comparison of lambda and Tenchu for control of rice stink bug (RSB) in Arkansas County. The black line represents the first and second weeks after 75% heading, the threshold is 5 RSB/10 sweeps. The orange line represents third and fourth weeks after 75% heading, the threshold is 10 RSB/10 sweeps.

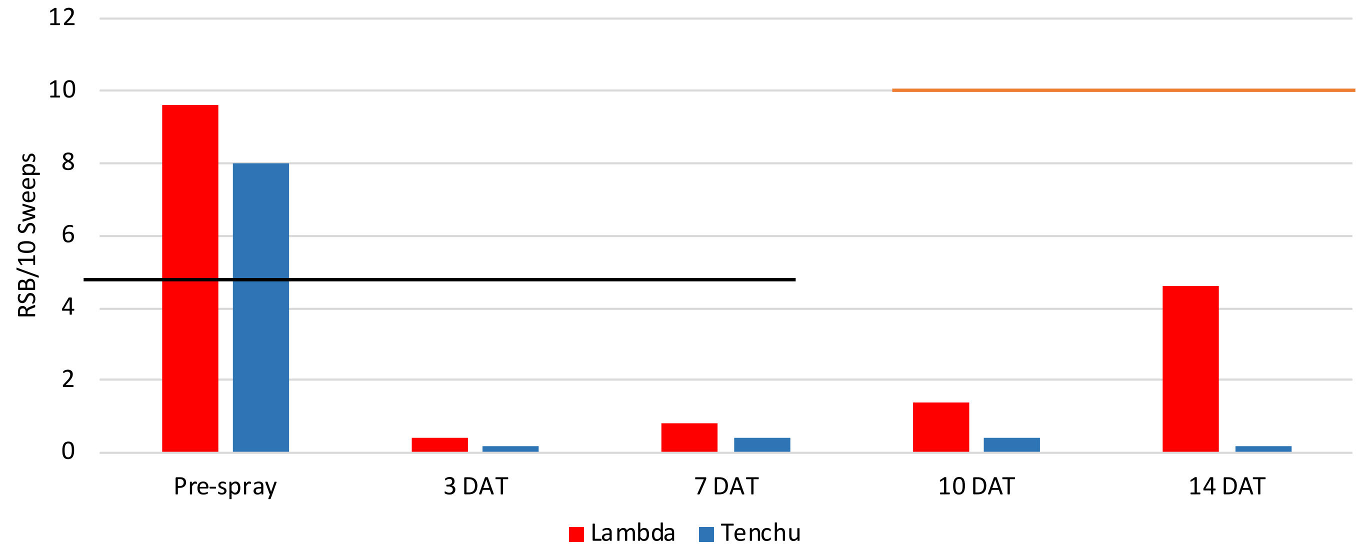

Fig. 2. Large block comparison of lambda and Tenchu for control of rice stink bug (RSB) in Faulkner County. The black line represents the first and second weeks after 75% heading, the threshold is 5 RSB/10 sweeps. The orange line represents the third and fourth weeks after 75% heading, the threshold is 10 RSB/10 sweeps.

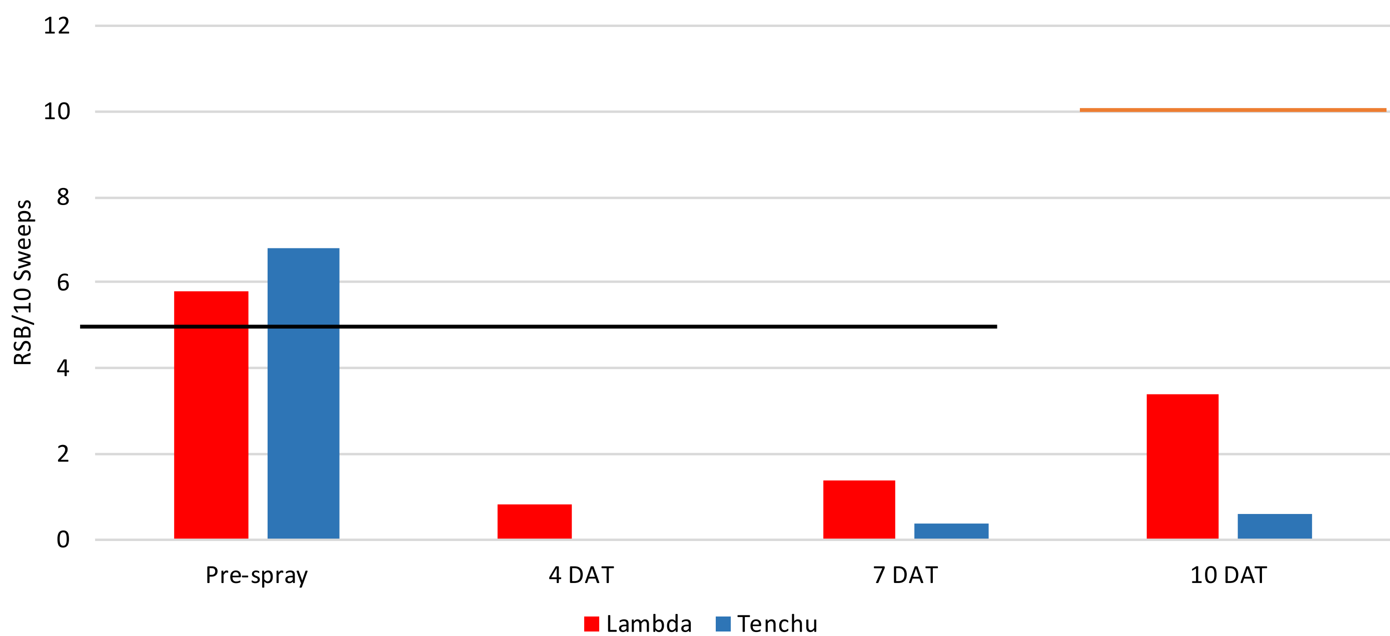

Fig. 3. Large block comparison of lambda and Tenchu for control of rice stink bug (RSB) in Crittenden County. The black line represents the first and second weeks after 75% heading, the threshold is 5 RSB/10 sweeps. The orange line represents the third and fourth weeks after 75% heading, the threshold is 10 RSB/10 sweeps.

Preliminary Observations of Potential Tolerance/Resistance to Pyrethroids in Rice Stink Bugs in Arkansas

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Abstract

Rice stink bugs are a major pest of rice after panicle emergence in Arkansas. Pyrethroids, particularly lambda-cyhalothrin (lambda), have been the primary insecticide used to control RSB for the past 15 years. Recently, there have been increasing concerns about potential pyrethroid resistance. Control failures were observed for lambda in September of 2019 in Poinsett County, Arkansas. Two populations of RSB were collected in 2020, where immatures survived multiple applications of lambda. In residual exposure bioassays, 58% mortality was observed for a 1X rate (1.86 oz/ac) of lambda. A 4X rate (7.44 oz/ac) resulted in only 62% mortality. These preliminary results indicate that pyrethroid insecticide resistance may become a problem in Arkansas, and further testing is needed to determine future management strategies.

Introduction

The rice stink bug (RSB), *Oebalus pugnax*, is the major pest in heading rice in Arkansas. In recent growing seasons, approximately 50% of rice acres were treated for this pest. Estimates suggest RSB costs producers $18.29/ac in losses + costs across the midsouth (Bateman et al., 2017). Rice stink bug causes yield loss during the flowering and milk stages and quality losses (pecky rice) during the soft dough and hard dough growth stages. If RSB densities average 5 or more per 10 sweeps during the first 2 weeks after heading, or an average of 10 or more per 10 sweeps during the third and fourth week after heading, an insecticide application is recommended (Lorenz et al., 2019).

Pyrethroids make up over 99% of all applications targeting RSB in Arkansas. Lambda-cyhalothrin is the most used pyrethroid for RSB control. Other pyrethroids such as zeta-cypermethrin (Mustang Maxx) and gamma-cyhalothrin (Declare or Prolex) are labeled for RSB control but are rarely used due to the cost-effectiveness of lambda-cyhalothrin. A neonicotinoid, dinotefuran (Tenchu), is labeled, but the cost is much higher than the pyrethroids, and it has not been widely adopted by growers (EPA Reg. No. 33657-17 et al., 2009). Rice stink bug resistance to pyrethroids has not been documented in Arkansas; however, problems with resistance have been reported in Texas (Miller et al., 2010; Blackman et al., 2015). The main objective of this study was to determine if there is a developing problem with pyrethroid insecticide resistance to rice stink bug in Arkansas.

Procedures

Field populations of rice stink bugs were collected from two different rice fields in Arkansas during 2020. The first collection site was in Chicot County, Arkansas, near Lake Village. This location was planted in RT XP753, and collections were made on 4 September 2020. The second collection location was in Crittenden County, Arkansas near Earle. This field was planted in RT 7321 FP, and collections were made on 21 September 2020. At all locations, collections of RSB were made following a failed lambda application by the grower. Approximately 450 RSBs were collected with sweep nets from each location. Rice stink bugs were transferred from the sweep net to rearing cages with rice plants inside to provide a food source. Rice stink bugs were transported to the laboratory at the University of Arkansas System Division of Agriculture's Lonoke Research and Extension Center, Lonoke, Arkansas, and held at 72 °F for 24 hours prior to bioassay initiation. Lambda-cyhalothrin (Warrior II) was applied to 4-in. Petri dishes at rates of 0 oz/ac (control, only water), 0.46 oz/ac (0.25X), 0.93 oz/ac (0.5X), 1.86 oz/ac (1X), 3.72 oz/ac (2X), and 7.44 oz/ac (4X). Lambda was applied to Petri-dishes with a backpack sprayer, using a 2-row hand boom, with TeeJet hollow cone tips calibrated to 10 GPA at 40 PSI. Each treatment was replicated 10 times. Five RSB adults were placed into each Petri dish after the insecticide had time to dry. Mortality was recorded 24 hours after RSB were placed into Petri dishes.

Results and Discussion

No treatment achieved 100% mortality for RSB collected from Chicot County, Arkansas. All treatments had greater mortality than the untreated check (UTC). The 1X, 2X, and 4X rates had higher mortality than the 0.25X and 0.5X rates. No differences were observed between 1X, 2X, and 4X rates of lambda for mortality of RSB (Fig. 1). Rice stink bugs collected from the Crittenden County, Arkansas location had greater mortality in all rates of lambda than the UTC. However, no differences were observed between any rates of lambda. The greatest level of mortality observed in this population was less than 60% (Fig. 2).

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Results from 2020 were similar to Lorenz et al. (2019) in 2019 in Poinsett County, Arkansas. In that study, assays receiving a 1X rate resulted in 40% mortality of the tested population, and a 4X rate was required to achieve 100% mortality. In both locations tested in 2020, 100% mortality was never achieved for any rate of lambda-cyhalothrin tested. In the 2019 and 2020 growing season, no rice stink bug control issues were observed prior to September. After the results of our assay, an informal survey was conducted with consultants around the area where problems were observed. Many of them indicated they also saw some degree of RSB nymph survival following pyrethroid applications. Observing RSB nymphs following a pyrethroid application in rice is a sign of poor control and potential problems.

Practical Applications

Assay results indicate that resistance/tolerance of RSBs to lambda may be a developing issue for Arkansas rice producers. All populations that were tested were behind failed lambda applications and were late in the growing season. No problems for rice stink bug control with lambda were observed prior to September. It is important to realize that these results are strictly preliminary and that more work must be done before we can definitively tell whether a problem is developing. We plan to continue our assays to determine the extent of these resistance/tolerance issues. If pyrethroid resistance is developing, we will need to educate our growers and consultants on sustainable insecticide resistance management. Further studies are required to test multiple insecticide products for efficacy and economic feasibility for controlling RSB.

Acknowledgments

The authors wish to express appreciation to Arkansas crop consultants and county agents for identifying problem fields. We also express our appreciation for funding and support from the Arkansas rice growers administered through the Rice Research and Promotion Board. Support was also given by the University of Arkansas System Division of Agriculture.

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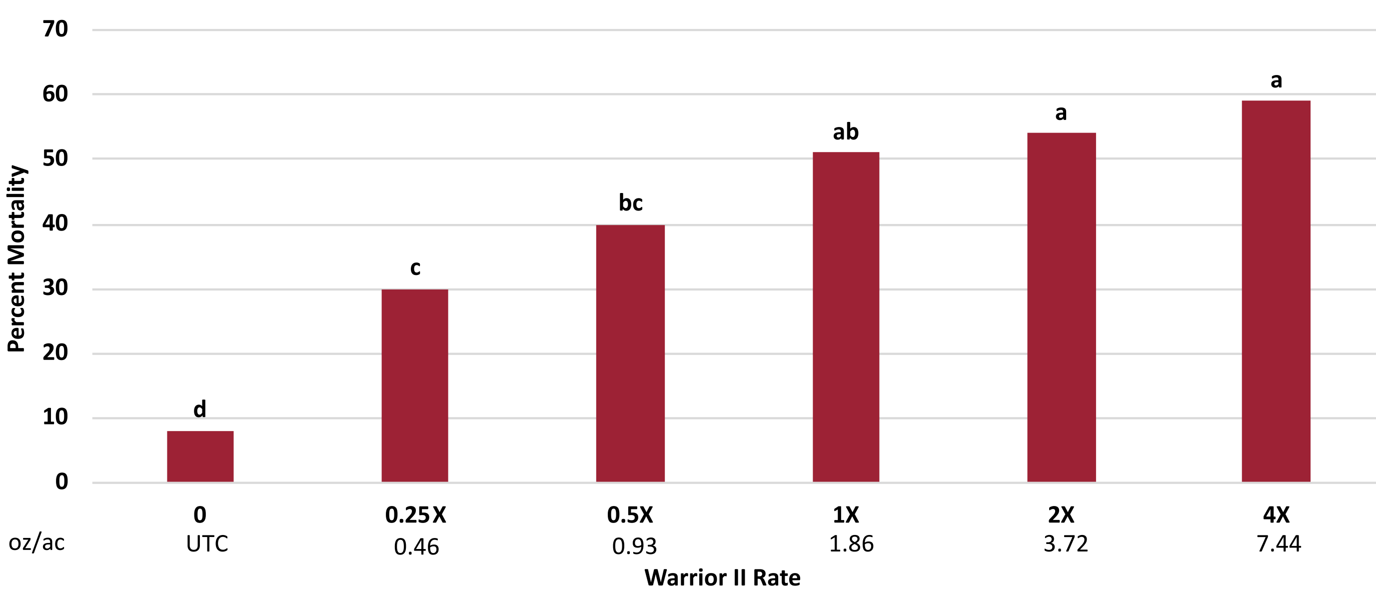

Fig. 1. Efficacy of lambda-cyhalothrin for rice stink bug control at multiple rates 24 hours after exposure. Chicot County, Arkansas, 2020. UTC = untreated check.

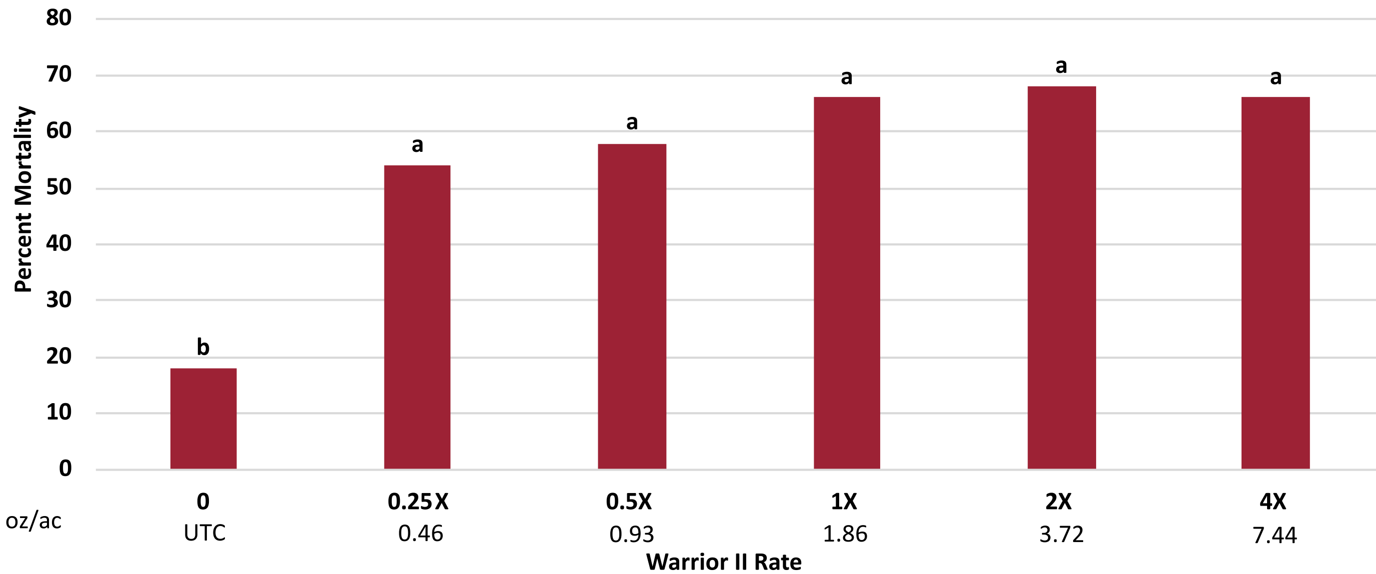

Fig. 2. Efficacy of lambda-cyhalothrin for rice stink bug control at multiple rates 24 hours after exposure. Crittenden County, Arkansas, 2020. UTC = untreated check.

Evaluation of Insecticide Seed Treatment Combinations for Control of Rice Water Weevil, *Lissorhoptrus oryzophilus*, in Arkansas

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Abstract

Grape colaspis and rice water weevil (RWW) are two of the most important pest of rice in Arkansas. The main control strategy for both of these pests is the use of insecticide seed treatments. CruiserMaxx Rice and NipsIt INSIDE, both neonicotinoids, have shown excellent control of grape colaspis but can have a short residual and not provide adequate control of rice water weevil. The diamides, Dermacor X-100 and Fortenza, provide excellent control of rice water weevil but do not provide adequate control of grape colaspis. Combining a neonicotinoid seed treatment and a diamide seed treatment may provide better control of the seedling pest complex compared to these products alone and may enhance overall RWW control when planting early in the spring when cool, wet weather delays growth and permanent flooding. The purpose of these trials was to evaluate the efficacy of insecticide seed treatment combinations for rice water weevils. These results indicated combinations of diamide and neonicotinoid insecticide seed treatments have the potential to reduce rice water weevil density and increase yield in conventional and hybrid rice cultivars.

Introduction

Insecticide seed treatments (ISTs) are used on 70–80% of rice acreage in Arkansas for control of rice water weevil (RWW), grape colaspis (GC), and other pests. In previous studies, ISTs have been shown to improve stand counts and increase yields 80% of the time (Taillon et al., 2015). These treatments are also convenient and provide a more reliable option for RWW control when compared to foliar applications (Taillon et al., 2013).

In Arkansas, when growers plant early while the weather is still cool and tends to be wet, permanent flood is often delayed. Neonicotinoid seed treatments such as thiamethoxam (CruiserMaxx) and clothianidin (NipsIt INSIDE) are very effective for early season control of GC, while diamides such as chlorantraniliprole (Dermacor) and cyantraniliprole (Fortenza) are not. Previous studies indicate the residual control for neonicotinoids is only about 28–35 days. Diamides are very effective for control of RWW and have a residual of 60–70 days or more (Taillon et al., 2017). This would indicate that a combination of a neonicotinoid and a diamide might provide better control of the seedling insect pest complex compared to these products alone and enhance control of RWW. The objective of this study was to evaluate combinations of ISTs for control of RRW in conventional and hybrid rice and to determine if combinations of ISTs would provide increased control of RWW and value for growers in Arkansas.

Procedures

Small plot trials were conducted at the University of Arkansas System, Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas, and at the Rice Research and Extension Center (RREC), near Stuttgart, Arkansas. The experimental plot design was a randomized complete block with 4 replications. The RT7301 hybrid and Diamond were planted at PTRS at 20 lb/ac and 70 lb/ac, respectively, and Diamond was planted at RREC at 70 lb/ac. Treatments included: Fungicide Only (UTC), NipsIt INSIDE® (clothianidin) 1.92 fl oz/cwt, CrusierMaxx® Rice (thiamethoxam) 7 oz/cwt, Dermacor® (chlorantraniliprole) 2.5 fl oz/cwt or 5 fl oz/cwt (conventional or hybrid, respectively), and Fortenza 3.47 oz/cwt, as well as combinations of NipsIt INSIDE + Dermacor, NipsIt INSIDE + Fortenza, NipsIt INSIDE + CruiserMaxx, CruiserMaxx + Dermacor, and CruiserMaxx + Fortenza.

Rice water weevil larvae were evaluated by taking 3 core samples per plot with a 4-inch core sampler 21 days after permanent flood establishment. Samples were evaluated at the Lonoke Agricultural Extension Center. Each core was washed into a 40-mesh sieve with water to loosen soil and remove larvae from the roots. The sieve was immersed in a warm saturated saltwater solution which caused the larvae to float for counting. Yield samples were collected and adjusted to 12% moisture. All data were processed using Agriculture Research Manager 2018.3 (Gylling Data Management, Inc., Brookings, S.D.) with Duncan's New Multiple Range Test ($P = 0.10$) to separate means.

Results and Discussion

Trial 1–(PTRS) RT7301–Rice Water Weevil Control

In the hybrid cultivar, all treatments reduced RWW compared to the untreated check. The combination of NipsIt INSIDE + Fortenza reduced RWW below NipsIt INSIDE, CruiserMaxx, or NipsIt INSIDE + Dermacor (Fig. 1).

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Trial 2–(PTRS) and Trial 3–(RREC) Diamond-Rice Water Weevil Control

In the conventional cultivar at PTRS, all treatments reduced RWW compared to the untreated check. Fortenza alone provided better control than all other treatments, and all other treatments provided more control than CruiserMaxx alone (Fig. 2). Similar trends were observed at RREC, although pressure was much lower, and little separation was observed among treatments (Fig. 3).

Yield

Yield was taken for each trial, and treatments did not separate statistically from the untreated check (Figs. 4–6). However, the observation was made that treatments can increase yield up to 15% compared to the untreated. In general, a trend was observed for higher yields when a combination of a neonicotinoid and diamide seed treatment was used compared to either class alone.

Practical Applications

These trials went through an extended growing season. RWW cores were sampled between 63 and 74 days after planting. Diamides such as Dermacor and Fortenza were shown to have greater residual control than the neonicotinoids, CruiserMaxx and NipsIt INSIDE. Combinations of ISTs have the potential to reduce RWW pressure and increase yield in conventional and hybrid rice varieties. Due to these findings, further studies will be conducted to evaluate the added benefit of IST combinations.

Acknowledgments

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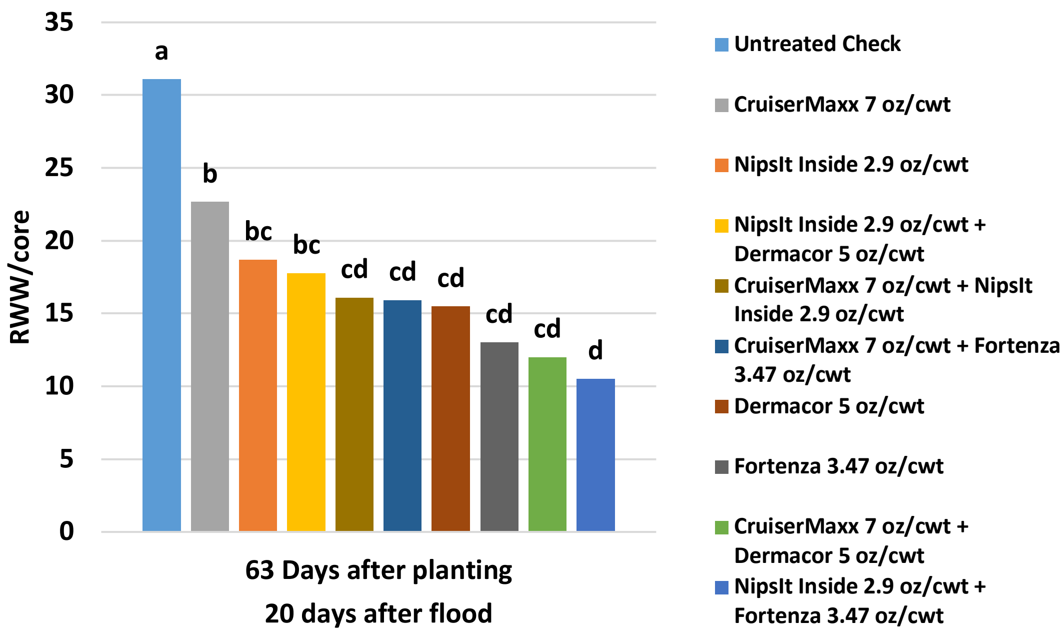

Fig. 1. Evaluation of insecticide seed treatment combinations for control of rice water weevil in hybrid rice at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, 2020.

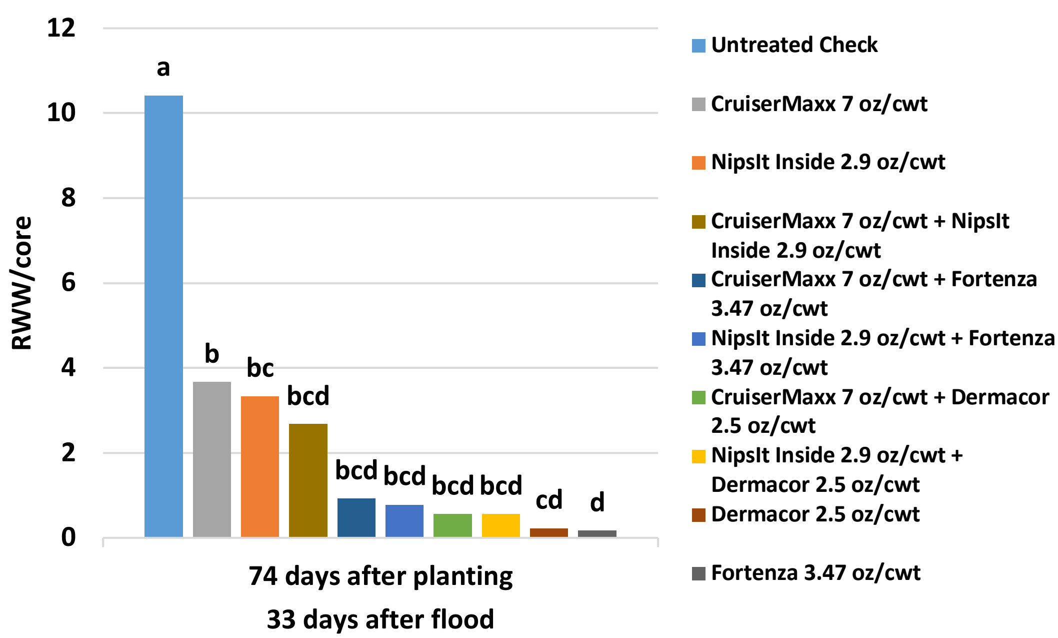

Fig. 2. Evaluation of insecticide seed treatment combinations for control of rice water weevil in conventional rice at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, 2020.

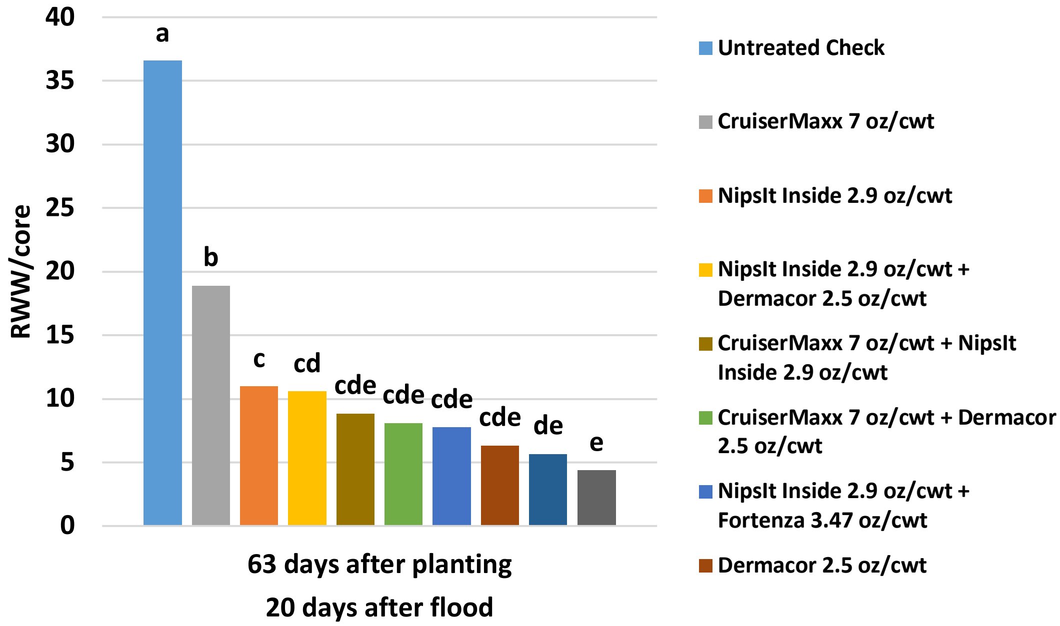

Fig. 3. Evaluation of insecticide seed treatment combinations for control of rice water weevil in conventional rice at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, 2020.

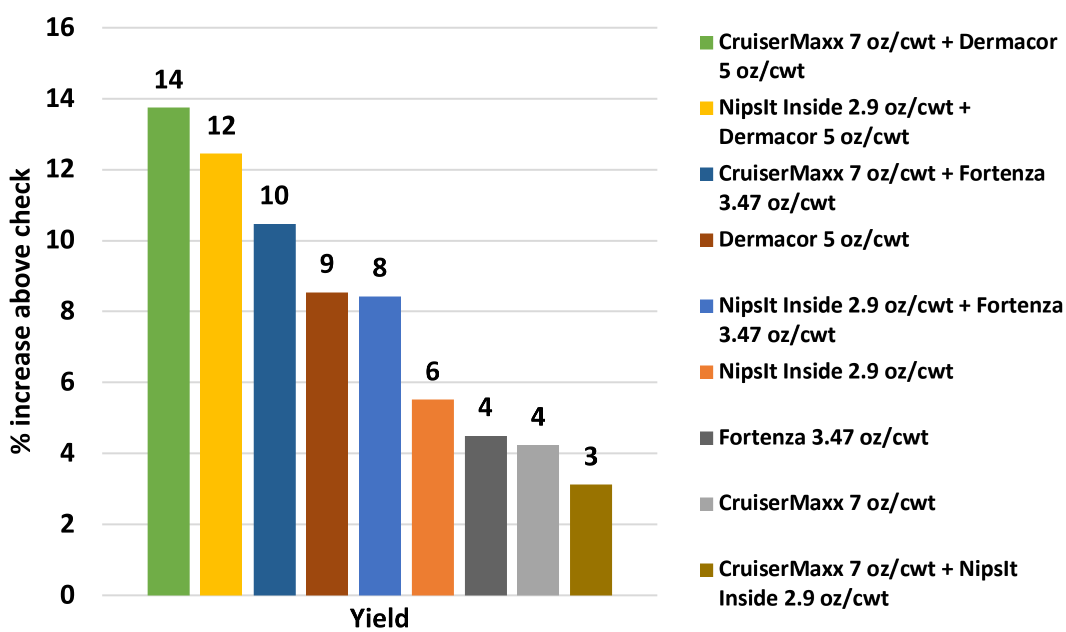

Fig. 4. Evaluation of insecticide seed treatment combinations for control of rice water weevil in hybrid rice at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, 2020. Yield increase above untreated check.

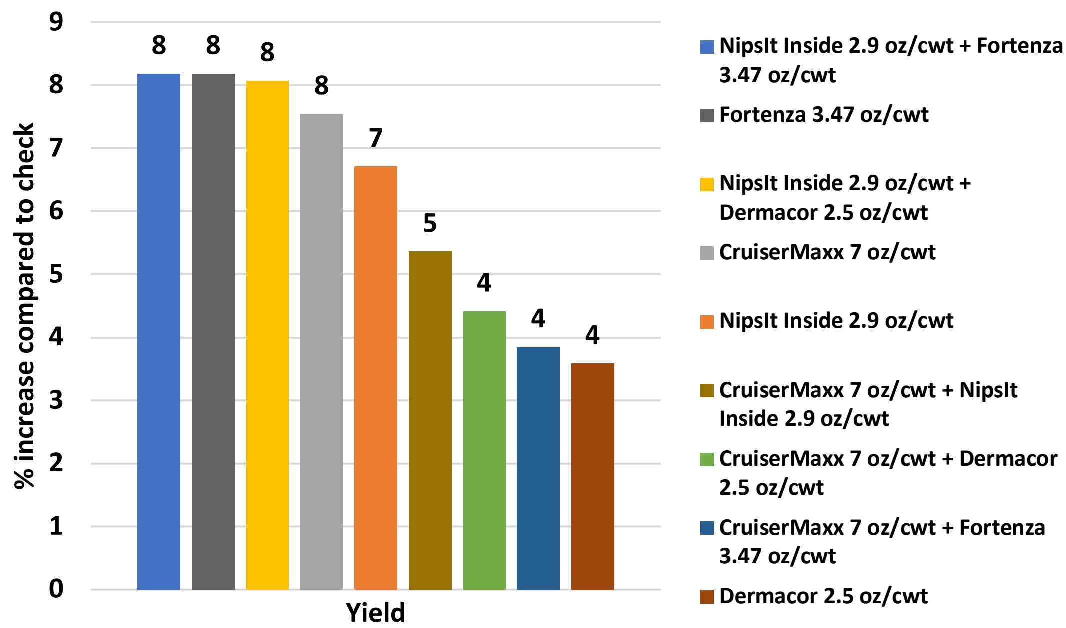

Fig. 5. Evaluation of insecticide seed treatment combinations for control of rice water weevil in conventional rice at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, 2020. Yield increase above untreated check.

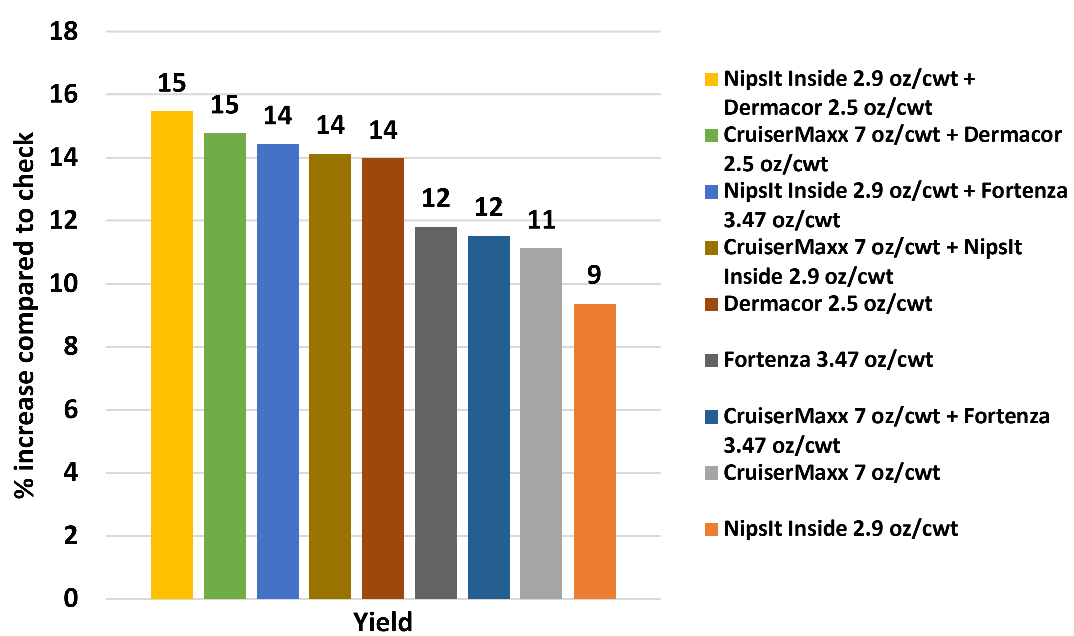

Fig. 6. Evaluation of insecticide seed treatment combinations for control of rice water weevil in conventional rice at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, 2020. Yield increase above untreated check.

Evaluation of 27 Rice Cultivars for Resistance to Stem Borers

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Abstract

Stem borers are minor pests of rice in Arkansas but can occasionally cause serious yield loss. Insecticide applications can be an effective control method for stem borers but can be expensive, and application timing is critical. A total of 27 rice cultivars were evaluated for resistance to stem borers. Plots were evaluated for stem borer injury by counting the total number of blank heads per plot at plant maturity. Results indicate a wide range of susceptibility across cultivars, with hybrids being less susceptible to injury than conventional varieties.

Introduction

The stem borer complex in Arkansas rice includes rice stalk borer (*Chilo plejadellus* Zincken) and sugarcane borer [*Diatraea saccharalis* (F.)]. Rice stalk borer is the most common of the two in Arkansas; however, both these insects are considered relatively minor pests in the state (Lorenz et al., 2018). Mexican rice borer [*Eoreuma loftini* (Dyar)] is an invasive rice borer species found in the southern U.S. It is currently only found in Louisiana and Florida but has the potential to become a pest in Arkansas. In 2018, it was estimated that 15% of rice acres in Arkansas were infested with rice stalk borer (Bateman et al., 2018). Resistance to stem borers has been recorded in some rice cultivars and can be an effective management tactic (Way et al., 2006). Stem borers are difficult to control after the larvae have entered the plant, and insecticide applications are not only expensive but difficult to time in order to achieve an effective level of control. This makes plant resistance an appealing control method for these pests.

Procedures

Plots were planted in Green County, Arkansas, on 1 May. A total of 27 conventional cultivars and hybrids, with 5 being medium grain and 22 being long grain, were included in the study. Plots were 8 rows wide on 7.5-in. row spacing, 16.5 ft long. Plots were arranged in a randomized complete block design with 4 replications. To evaluate stem borer injury, the total number of blank heads was recorded per plot and plant maturity. Data were analyzed using PROC GLIMMIX, SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.).

Results and Discussion

The mean number of blank heads per plot ranged from 14 for RT7231M to 462 in DGL2065, with an average across all cultivars of 93 per plot (Fig. 1). There were no differences in susceptibility between long-grain and medium-grain varieties; however (Fig. 2), conventional varieties were much more susceptible to stem borer damage than hybrids (Fig. 3).

Practical Applications

Rice stem borers have been increasing in Arkansas over the past few years. Some of this could be due to continuous rice production rotation practices in parts of the state. Growers with a history of stem borers can use this data to select a cultivar that is less susceptible in the future.

Acknowledgments

This research was funded by the Arkansas Rice Checkoff Program, administered by the Arkansas Rice Research and Promotion Board.

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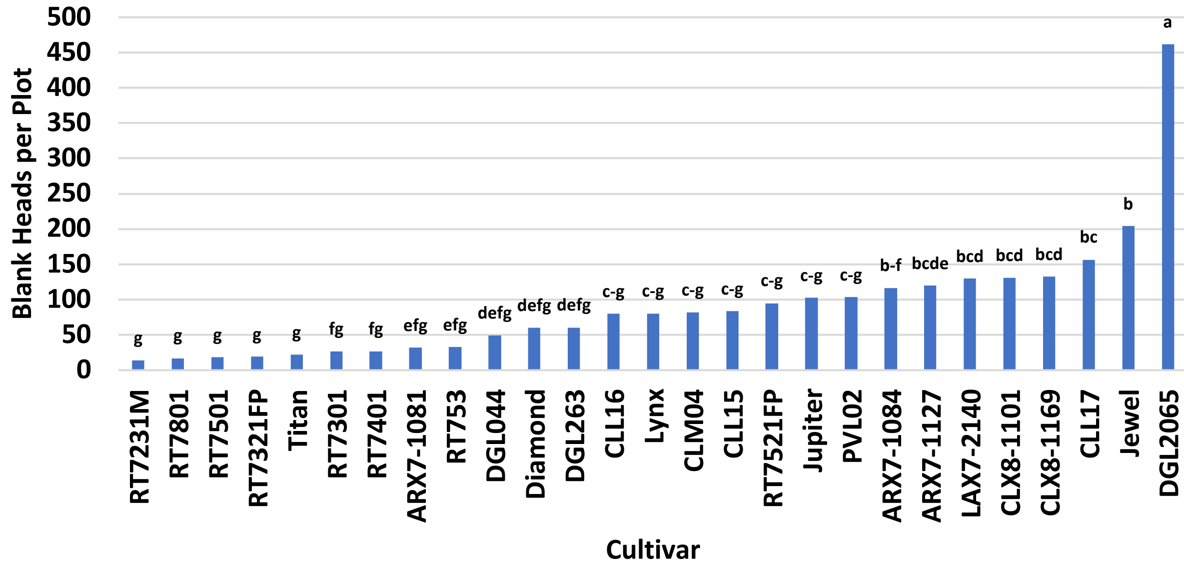

Fig. 1. The mean number of blank heads per plot by cultivar. Means followed by the same letter are not significantly different (*P* ≤ 0.05).

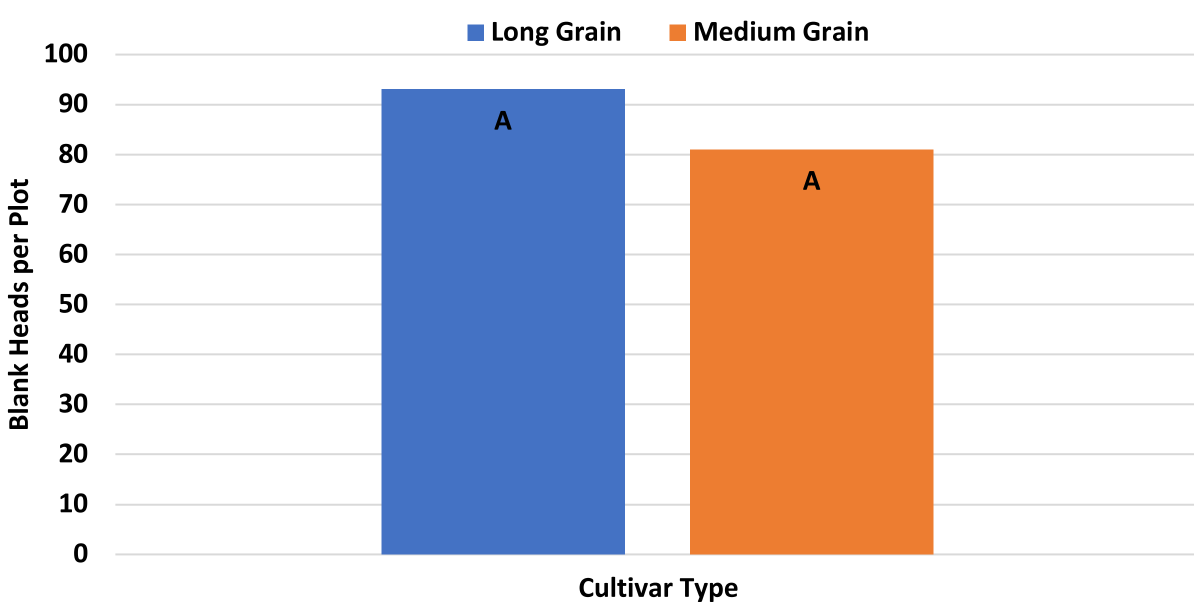

Fig. 2. Comparison of long-grain and medium-grain cultivar's susceptibility to rice stem borer. Means followed by the same letter are not significantly different (*P* ≤ 0.05).

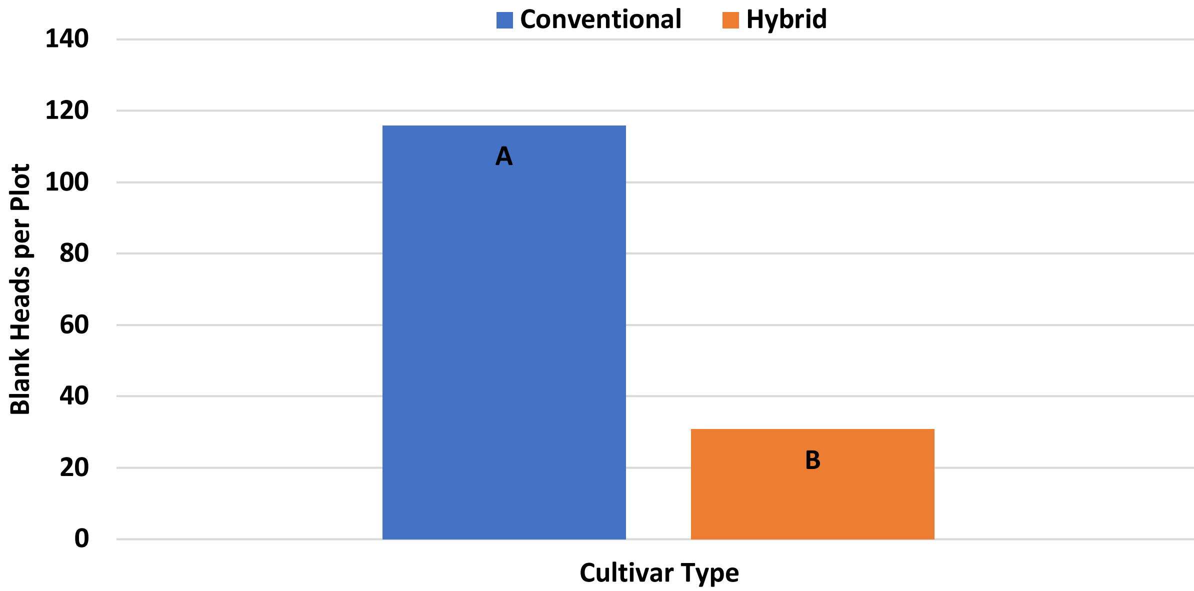

Fig. 3. Comparison of conventional and hybrid cultivar's susceptibility to rice stem borer. Means followed by the same letter are not significantly different ($P \leq 0.05$).

Chloroacetamide Herbicide Use for Weed Control in Rice

T.H. Avent,[1] J.K. Norsworthy,[1] L. Piveta,[1] M.C. Castner,[1] and J.W. Beesinger[1]

Abstract

Acetochlor has been shown to be an effective option for controlling barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.]; however, the herbicide is currently not labeled for use in rice. Field trials were initiated in the spring of 2020 at the Rice Research and Extension Center that evaluated rice tolerance to acetochlor using a fenclorim seed treatment as well as the control of barnyardgrass and weedy rice [*Oryza sativa* (L.)] with a microencapsulated formulation of acetochlor (Warrant). The experiment was a three-factor randomized complete block design. The three factors evaluated included fenclorim seed treatment (none and 2.5 lb ai/1000 lb seed), acetochlor application timings (preemergence (PRE), delayed-preemergence (DPRE), spiking, and 1-leaf), and acetochlor rates (0, 0.56, 1.12, and 1.68 lb ai/ac). As the rate of acetochlor increased, injury to rice increased; however, the fenclorim seed treatment reduced injury of rice at 21 days after treatment (DAT) from 33% and 54% to 13% and 20% for acetochlor rates of 1.12 and 1.68 lb ai/ac, respectfully. Likewise, as the rate of acetochlor increased, averaged over application timings and fenclorim use, barnyardgrass control increased at 21 DAT, with an average control of 65%, 71%, and 82% for 0.56, 1.12, and 1.68 lb ai/ac, respectively. For weedy rice control, earlier application timings provided greater control for the low and middle rates of acetochlor, but the highest rate of acetochlor was not significantly better at other application timings. Furthermore, the fenclorim seed treatment did not influence barnyardgrass or weedy rice control. From this research, it appears that a fenclorim seed treatment provides enhanced safety for applications of microencapsulated acetochlor in rice without compromising barnyardgrass and weedy rice control.

Introduction

Currently, very-long-chain fatty acid-elongase inhibitors (WSSA group 15) are not labeled for use in United States (U.S.) rice production; however, the herbicide pretilachlor has been used in Asian rice production systems with great success (Chen et al., 2012). Like pretilachlor, acetochlor is a chloroacetamide herbicide, and acetochlor is commonly used in U.S. soybean and cotton production for preemergence control of small-seeded broadleaves and grasses (Babzinski et al., 2012). Recently, The University of Arkansas System Division of Agriculture has demonstrated the utility of using acetochlor for weed control in rice (Norsworthy et al., 2019). Preemergence (PRE) and delayed-preemergence (DPRE) applications of the microencapsulated (ME) formulation of acetochlor provided substantial control of barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.]; however, at PRE and DPRE application timings, unacceptable stand loss and injury to rice occurred. In Arkansas, acetochlor would provide an alternative site of action for herbicide-resistant weeds in rice and control of weedy rice [*Oryza sativa* (L.)], sprangletop (*Leptochloa* spp.), and barnyardgrass, three of the five most problematic weeds for Arkansas rice producers (Norsworthy et al., 2007).

In the 1980s, Ciba Geigy developed a herbicide safener known as fenclorim to mitigate undesirable injury and stand loss from the herbicide pretilachlor (Quadranti and Ebner, 1983). Initially, the herbicide and safener were sold as a premix under the trade name of Sofit®. Today, rice seeds are typically soaked in a water/fenclorim solution before being water-seeded or transplanted (Chen et al., 2012).

Fenclorim safens applications of chloroacetamides by upregulating genes responsible for producing glutathione *S*-transferase (GST) enzymes that are paramount in the detoxification of chloroacetamide herbicides (Usui et al., 2000). This upregulation speeds up the metabolism of herbicides like pretilachlor and acetochlor, which reduce the injury and stand loss typically caused by these herbicides in rice. Based on this knowledge, a fenclorim seed treatment was added to drill-seeded rice to safen applications of a microencapsulated acetochlor. The purpose of this experiment was to determine the level of weedy rice and barnyardgrass control with acetochlor and the safening effects provided by the fenclorim seed treatment.

Procedures

A field study was conducted in 2020 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Arkansas. The primary objective was to evaluate weed control with various rates and timings of acetochlor. Furthermore, the experiment was designed to evaluate rice tolerance to various rates and application timings of acetochlor with and without a fenclorim seed treatment. The experiment was designed as a three-factor factorial randomized complete block design. The three factors evaluated included the fenclorim seed treatment (none and 2.5 lb ai/1000 lb seed),

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acetochlor application timings (PRE, DPRE, spiking, and 1-leaf), and acetochlor rates (0, 0.56, 1.12, and 1.68 lb ai/ac). Acetochlor applications were applied to a silt loam soil with a CO_2-pressurized backpack sprayer calibrated to apply 15 GPA at 3 MPH with AIXR 110015 nozzles. PRE applications were applied at planting and DPRE applications were made 3 days after planting. 'Diamond' rice was planted at 22 seeds ft/row. Evaluations included percent weed control and visual injury 14, 21, and 28 days after each treatment (+/-3 days) and rough rice yield collected at harvest. All data were subjected to analysis of variance, and means were separated using Fisher's protected least significant difference (α = 0.05) using JMP Pro 15.2.

Results and Discussion

During the evaluations of this experiment, fenclorim did not influence weed control (Table 1). At 21 days after treatment (DAT), earlier application timings of acetochlor improved control of barnyardgrass, with DPRE applications being better than spiking and 1-leaf application timings (Table 2). Furthermore, acetochlor applied PRE and DPRE, averaged across seed treatment and acetochlor rates achieved 80% and 83% barnyardgrass control, respectively. For weedy rice control, a significant interaction showed that 0.56 and 1.12 lb ai/ac did not exceed 31% control for spiking and 1-leaf applications. At all application timings, 1.68 lb ai/ac achieved greater than or equal to 55% weedy rice control, with all being statistically similar. Preemergence and DPRE applications of 1.12 lb ai/ac also exceeded 55% control of weedy rice. For injury 21 DAT and averaged over application timings, Fenclorim significantly reduced injury for acetochlor rates of 1.12 and 1.68 lb ai/ac (Table 3). Additionally, 1.12 and 1.68 lb ai/ac did not exceed 20% injury, which is deemed as commercial tolerance. In terms of yield, averaged over fenclorim, PRE, DPRE, and Spiking applications of acetochlor rates of 1.12 and 1.68 lb ai/ac yielded better than 0.56 lb ai/ac and 1-leaf applications of acetochlor which can be attributed to reduced weed control (Table 4). Lastly, averaged over acetochlor rates and application timings, the presence of the fenclorim seed treatment increased yield from 145 to 162 bu./ac indicating a significant safening effect.

Practical Applications

Acetochlor (Warrant) which is currently not labeled for U.S. rice production would provide an alternative site of action for Arkansas rice growers to help combat widespread herbicide resistance. This herbicide would also provide an alternative residual herbicide to control clomazone-resistant barnyardgrass. Furthermore, the fenclorim seed treatment combined with acetochlor applications provide a non-traited control option for weedy rice that carries no risk of backcrossing into the weedy rice population. Commercial tolerance was achieved at the DPRE application timing of acetochlor with 1.12 lb ai/ac and with the fenclorim seed treatment. These findings demonstrate the safening potential of the fenclorim seed treatment, as well as the lack of influence the seed treatment has on weed control.

Acknowledgments

Support for weed management research in rice was provided by the Arkansas rice checkoff program administered by the Arkansas Rice Research and Promotion Board is gratefully appreciated. Support also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Analysis of variance table with *P*-values for control and injury 21 days after treatment and yield.

Effect	Barnyardgrass	Weedy rice	Injury	Yield
Herbicide	0.0094	<0.00001	<0.00001	<0.00001
Timing	0.0002	<0.00001	<0.00001	<0.00001
Fenclorim	0.7535	0.3115	<0.00001	0.00012
Herbicide*timing	0.7283	0.0183	0.0321	0.0183
Herbicide*fenclorim	0.8245	0.7565	<0.00001	0.26005
Timing*fenclorim	0.5764	0.7762	0.0193	0.82145
Herbicide*timing*fenclorim	0.9486	0.9963	0.80003	0.63502

Table 2. Weedy rice and barnyardgrass control 21 days after treatment plus or minus 3 days.

		Visual weed control	
Application timing	Acetochlor rate	BYG[†] control	WR[‡] control
	(lb ai/ac)	-------------------%-------------------	
Preemergence	0.56		36 cd
	1.12	80 ab[§]	56 ab
	1.68		60 ab
Delayed-Preemergence	0.56		47 bc
	1.12	83 a	71 a
	1.68		63 ab
Spiking	0.56		15 e
	1.12	69 bc	27 cde
	1.68		59 ab
1-Leaf	0.56		31 cde
	1.12	58 c	22 de
	1.68		55 ab

[†] Barnyardgrass control averaged over acetochlor rates.
[‡] Weedy rice or red rice.
[§] Different letters within a column indicate a significant difference between treatments; means separated using Fisher's protected least significant difference test at α = 0.05.

Table 3. Cultivated rice injury averaged over application timing 21 days after treatment plus or minus 3 days.

Acetochlor rate	Fenclorim SDTR[†]	Visual injury
(lb ai/ac)	(lb ai/1000 lb-seed)	%
0.56	0	11 cd[‡]
	2.5	6 d
1.12	0	32 b
	2.5	15 cd
1.68	0	55 a
	2.5	19 c

[†] SDTR = seed treatment.
[‡] Different letters within a column indicate a significant difference between treatments; means separated using Fisher’s protected least significant difference at α = 0.05.

Table 4. Estimated rough rice yield collected at harvest averaged over fenclorim seed treatment and averaged over application timing and acetochlor rate, respectively.

Application timing	Acetochlor rate	Yield
	(lb ai/ac)	**bu./ac**
Preemergence	0.56	137 cd[†]
	1.12	177 a
	1.68	180 a
Delayed-Preemergence	0.56	150 bc
	1.12	169 ab
	1.68	175 a
Spiking	0.56	147 c
	1.12	171 a
	1.68	178 a
1 - Leaf	0.56	123 d
	1.12	122 d
	1.68	120 d
Fenclorim SDTR[‡]		**Yield**
(lb ai/1000 lb-seed)		**bu./ac**
0		145 b
2.5		162 a

[†] Different letters within a column indicate a significant difference between treatments; means separated using Fisher's protected least significant difference at $\alpha = 0.05$.

[‡] SDTR = seed treatment.

Effect of Environmental Conditions on Rice Injury Caused by Florpyrauxifen-benzyl

J.W. Beesinger,[1] J.K. Norsworthy,[1] T.L. Roberts,[1] L.T. Barber,[2] and T.R. Butts[2]

Abstract

Florpyrauxifen-benzyl (Loyant) has caused variable injury in rice (*Oryza sativa* L.) since the commercial release of the herbicide in 2018. Environmental conditions have been proven to influence the efficacy of florpyrauxifen-benzyl and other herbicides; therefore, it is hypothesized that environmental conditions could impact the magnitude of injury to rice caused by florpyrauxifen-benzyl as well. A greenhouse study was conducted to determine the effect of soil moisture at the time of application on rice injury caused by florpyrauxifen-benzyl. Buckets of soil were watered to desired levels of 60%, 80%, and 100% of pore space filled by water. Rice cultivar Rice Tec XP753, known to be sensitive to florpyrauxifen-benzyl, was planted in the buckets and maintained at the desired soil moisture level. An application of 16 oz/ac of florpyrauxifen-benzyl was made when rice reached the 4- to 5-leaf growth stage. In a growth chamber experiment, buckets of soil containing the rice cultivar RT XP753 were maintained in a similar manner, but all treatments were watered to 100% field capacity. Prior to application, buckets were placed in a growth chamber at a low (700 µmol/m/s) or high light intensity (1200 µmol/m/s). The soil in both experiments was flooded to a 2-in. depth 5 days after application. Visual estimations of injury were taken weekly until 28 days after application, after which aboveground biomass was harvested and dried. Rice treated with florpyrauxifen-benzyl maintained at a soil moisture of 100% displayed the most visible injury and subsequent biomass reduction. There was more injury to rice under the low than high light intensity. Producers should be aware that applications of florpyrauxifen-benzyl under saturated conditions or low light intensity such as prolonged cloud cover can be more injurious and that avoiding these environmental conditions could reduce the potential for injury.

Introduction

Florpyrauxifen-benzyl (Loyant) was labeled in 2018 to combat several problematic weed species in Arkansas rice production (Anonymous 2018). Producers rely on the registration of new sites of action to combat the ever-growing problem of herbicide resistance. Following the commercial launch of florpyrauxifen-benzyl, producers, consultants, and scientists observed varying rice tolerance to florpyrauxifen-benzyl. Rice injury was observed across cultivar, soil type, and environmental conditions near the time of herbicide application. Wright et al. (2020) discovered that sequential applications of florpyrauxifen-benzyl to hybrid rice could cause yield loss in certain situations. Herbicide activity can be affected by environmental conditions. For example, the filtering of ultraviolent light for periods after application has been observed to increase the efficacy of certain acetyl CoA carboxylase-inhibiting herbicides on grassy species (McMullan 1996). Miller and Norsworthy (2018) observed higher levels of translocation and improved efficacy of florpyrauxifen-benzyl when applied to weedy species under moist soil conditions. It is unknown if higher amounts of translocation caused by increased soil moisture or a reduction in light intensity following applications of florpyrauxifen-benzyl could increase the amount of visual injury observed. Understanding how to minimize injury caused by florpyrauxifen-benzyl using factors that can be controlled while maximizing efficacy could allow producers to keep using the new site of action while reducing the potential for yield loss or delayed canopy development. The objectives of this research were to determine the effect of soil moisture and light intensity on rice injury caused by florpyrauxifen-benzyl.

Procedures

The first experiment, conducted in the greenhouse at the University of Arkansas System Division of Agriculture's Altheimer Laboratory in Fayetteville, Arkansas, was designed as a two-factor factorial randomized complete block design with three replications. The first factor consisted of three moisture levels (60%, 80%, and 100% of pore space filled by water) and the second factor was with or without an application of florpyrauxifen-benzyl. A silt loam soil collected from Fayetteville, Arkansas, was analyzed using SPAW (Soil Plant Air Water) software to determine the matric potential, bulk density, and field capacity. Air-dried soil weighing 17.6 lb was added to 2-gallon buckets, and water was added to each bucket based on the weight of the bucket and the determined soil bulk density to achieve the desired soil water content for each treatment. Rice cultivar RT XP753 was planted in each bucket and was watered to the desired level of field capacity every three days (6 buckets per treatment). Florpyrauxifen-benzyl at 16 oz/ac plus methylated seed oil at 8 oz/ac were applied to the "treated" buckets when rice reached the 4- to 5-leaf stage. Moisture levels were maintained until all buckets were flooded for 5 days after the application.

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Another two-factor factorial randomized complete block design experiment was conducted in a growth chamber at the University of Arkansas System Division of Agriculture's Altheimer Laboratory, Fayetteville, Arkansas. The first factor was light intensity with treatments of high light intensity (1200 µmol/m/s) and low light intensity (700 µmol/m/s). The second factor in the study was with or without an application of florpyrauxifen-benzyl. Light levels in the growth chamber were achieved by dividing the chamber in half using a curtain and altering the light output for each side. The growth chamber was programmed for a 12-hour day/night cycle at 95/75 °F respectively. The buckets for this experiment were started similar to the methods used in the greenhouse experiment; however, all treatments were maintained at 100% field capacity, which represents saturated soil conditions. Herbicide application rate, growth stage at application (timing of application), and moisture management following application were similar to the greenhouse experiment.

Both trials were visually rated for rice injury at 14, 21, and 28 days after florpyrauxifen-benzyl application. Aboveground biomass was collected at 28 days after treatment, dried to constant mass, and weighed. Means were subjected to analysis of variance and separated using Fisher's protected least significant difference ($\alpha = 0.05$). Biomass data from the soil moisture trial were subjected to T-tests to determine differences between treated and nontreated samples.

Results and Discussion

Rice treated with florpyrauxifen-benzyl and grown in buckets with soil moisture maintained at 100% field capacity showed more visible injury (37%) than treatments maintained at lower soil moistures (20% to 28% injury) (Table 1). Injury was lowest when soil moisture was 60% of field capacity, which was the driest soil moisture treatment included in the trial. Aboveground biomass was reduced only when rice was treated with florpyrauxifen-benzyl and the soil moisture was maintained at 100% field capacity, possibly due to increased translocation in rice, as was observed in weed species (Miller and Norsworthy, 2018).

There was greater visible florpyrauxifen-benzyl injury observed under the low light regime (38%) than the high light intensity (20%) (Table 2). Relative biomass reflected these differences with the low light treatment causing a 22% reduction in biomass while florpyrauxifen-benzyl applied under the high light intensity only decreased relative biomass by 8%. Decreased amounts of injury at higher light intensity could have been the result of an increase in the rate at which the rice was growing, diluting the amount of florpyrauxifen-benzyl in the plant or degradation of the herbicide from the light.

Practical Applications

Findings from these experiments reveal that applying florpyrauxifen-benzyl onto saturated silt loam soils that remain wet or saturated and in low light intensity conditions increases the risk for rice injury from applications of florpyrauxifen-benzyl and resulted in the subsequent biomass reduction of treated rice. Current best management practices for preflood nitrogen application insist that water should not be present in a field when applied. If cloudy weather conditions are forecast to produce low light intensity for several days, growers will need to consider the potential of florpyrauxifen-benzyl injury to rice and weigh the pros and cons of delaying the application or consider alternative management practices.

Acknowledgments

Support for this research from the Arkansas Rice Research and Promotion Board is greatly appreciated. Appreciation is also extended to the hourlies and graduate students at the Altheimer Laboratory for their assistance in maintaining and collecting data from these trials.

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Table 1. Effect of florpyrauxifen-benzyl (Loyant) injury on rice as a result of soil moisture status at the time of application.

Field Capacity	Injury 28 DAT‡	Biomass† Nontreated	Biomass† Treated
---------------------------%---------------------------		---------------------oz---------------------	
60	20 c§	0.71	0.46
80	25 b	0.81	0.60
100	37 a	0.63	0.25*

† Means followed by an asterisk (*) designate difference from the nontreated check within the same row at *P* = 0.05.
‡ DAT= Days after treatment.
§ Means followed by the same letter are not significantly different at *P* = 0.05.

Table 2. Visual injury (%) and biomass reduction to rice grown under low and high light regimes 28 days after treatment with florpyrauxifen-benzyl at 16 oz/ac.

Treatment	Injury	Relative Biomass†
	----------------------%----------------------	
High Light Intensity (1200 μmol/m/s)	20 b‡	93 b
Low Light Intensity (700μmol/m/s)	38 a	78 a

† Biomass of treated samples made relative to nontreated checks for each treatment.
‡ Means within a column followed by the same letter are not significantly different at *P* = 0.05.

White-Margined Flatsedge (*Cyperus flavicomus* Michx.): Controlling This New Problematic Weed in Arkansas Rice

T.R. Butts,[1] B.M. Davis,[1] L.T. Barber,[1] J.K. Norsworthy,[2] and L.M. Collie[1]

Abstract

White-margined flatsedge is a relatively new problematic sedge species in Arkansas rice that is spreading across the state with little to no research available on effective control strategies. The objective of this research was to evaluate and identify burndown, preemergence (PRE), and postemergence (POST) herbicide options to control white-margined flatsedge in rice. Two on-farm field studies (Light, Arkansas) evaluating burndown and PRE herbicides and one greenhouse study (Lonoke, Arkansas) evaluating POST herbicides were conducted in 2020. Roundup PowerMax (glyphosate) at 32 oz/ac and Gramoxone (paraquat) at 64 oz/ac were the best burndown herbicides to control white-margined flatsedge, providing >95% control 4 weeks after application (WAA). Bolero (thiobencarb) at 4 pt/ac delayed-PRE and Sharpen (saflufenacil) at 3 oz/ac PRE provided the greatest and most consistent residual control (85% and 81%, respectively) of white-margined flatsedge in the PRE study. Basagran (bentazon) at 2 pt/ac plus 1% v/v crop oil concentrate and Loyant (florpyrauxifen-benzyl) at 8 and 16 oz/ac plus methylated seed oil at 0.5 pt/ac were the most effective POST herbicide options (≥90% control) for controlling this problematic weed species in the greenhouse study. As with other weeds, successful management of white-margined flatsedge requires the use of multiple effective herbicide options and applying POST herbicides well-timed when plants are small.

Introduction

Sedges, including yellow nutsedge (*Cyperus esculentus* L.) and rice flatsedge (*Cyperus iria* L.), were listed in the top 15 important weeds of rice as reported by crop consultants in a 2011 survey (Norsworthy et al., 2013). Additionally, rice flatsedge and yellow nutsedge have been confirmed resistant to acetolactate synthase (ALS) inhibitors in Arkansas, making these weeds even more problematic to successfully control in rice (Heap, 2021; Riar et al., 2015). A relatively new problematic sedge, white-margined or white-edge flatsedge (*Cyperus flavicomus* Michx.), has broadened its distribution across Arkansas and become increasingly troublesome to successfully control in rice (*Oryza sativa* L.). Its prolific growth habits and lack of information on appropriate herbicides have provided opportunities for this weed species to thrive in a rice cropping system. The objective of this research was to evaluate and identify burndown, preemergence (PRE), and postemergence (POST) herbicide options to control white-margined flatsedge in rice.

Procedures

Two on-farm field studies (Light, Arkansas) evaluating burndown and PRE herbicides and one greenhouse study (Lonoke, Arkansas) evaluating POST herbicides were conducted in 2020. Ten and thirteen common rice herbicides used in Arkansas were evaluated in the PRE and POST studies, respectively, and 4 burndown herbicides were tested (Table 1). The PRE and POST studies were each conducted as a randomized complete block with a minimum of 3 replications and a nontreated control for comparison. The PRE study site was selected based on previous field history provided by the farmer and crop consultant and was sprayed 1 day after the farmer planted RT XP753 in the last week of April. No weeds had emerged at the time of application. In the POST greenhouse study, 12-in. × 12-in. × 2-in. trays were filled with potting mix, and white-margined flatsedge seeds were sown. Each tray served as an experimental unit and contained a minimum of 10 individual plants. Treatments were then applied once the white-margined flatsedge plants were 6-in. tall. The burndown study was conducted as an on-farm demonstration with only 1 replication and a nontreated control for comparison. White-margined flatsedge plants were sprayed when 2-in. tall.

Treatments across all trials were applied using a CO_2 pressurized backpack sprayer equipped with AIXR110015 nozzles calibrated to deliver 10 GPA. Visual estimates of weed control (0% = no control, 100% = complete plant death) were taken for treatment comparisons. Data from the PRE and POST studies were subjected to analysis of variance with means separated using Fisher's protected least significant difference test at α = 0.05. Data from the burndown demonstration were not subjected to statistical analysis due to only one replication, and therefore, were strictly observational.

Results and Discussion

Roundup PowerMax (glyphosate) at 32 oz/ac and Gramoxone (paraquat) at 64 oz/ac were the best burndown herbicides to control white-margined flatsedge providing >95% control 4 weeks after application (WAA) in the burndown demonstration conducted near Light, Arkansas (Fig. 1). Sharpen (saflufenacil) at

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3 oz/ac and 2,4-D LV4 (2 pt/ac) each controlled white-margined flatsedge 80% and 70%, respectively. Once again, this was strictly observational data from one replication at one site, so minimal definitive conclusions should be drawn.

Bolero (thiobencarb) at 4 pt/ac applied delayed-PRE provided the greatest residual control (85%) of white-margined flatsedge 6 WAA in the PRE study conducted near Light, Arkansas (Fig 2). Sharpen at 3 oz/ac was the next most effective PRE residual herbicide (81% control) and was statistically similar to Bolero. Facet L (quinclorac) at 43 oz/ac and Permit Plus (halosulfuron + thifensulfuron) at 0.75 oz/ac each provided ≥70% control of white-margined flatsedge 6 WAA; however, control was less consistent compared to Bolero and Sharpen.

At 3 WAA, Basagran (bentazon) at 2 pt/ac, Loyant (florpyrauxifen-benzyl) at 8 and 16 oz/ac, and 2,4-D LV4 at 2 pt/ac were the best options to effectively control white-margined flatsedge (>90% control) (Fig. 3). However, as exhibited in the burndown demonstration, 2,4-D LV4 may exhibit variable levels of control. If white-margined flatsedge is less than 6-in. tall at the time of application and the density is low, the rate of Loyant can be reduced to 8 oz/ac, and effective control can still be achieved (90%). If sedges are greater than 6 in. and/or the population is dense, the rate of Loyant should be increased accordingly up to the 16 oz/ac rate. Propanil (4 qt/ac), Permit Plus (0.75 oz/ac), Newpath (imazethapyr) (6 fl oz/ac), Gambit (halosulfuron + prosulfuron) (2 oz/ac), and Facet L (32 fl oz/ac) all provided marginal control (≥50% but less than 70%) at 3 WAA. However, they may be viable tank-mixture options with Basagran to provide multiple effective modes-of-action. Further research is required to identify tank-mixture options that can effectively control white-margined flatsedge and not exhibit antagonism.

Practical Applications

Overall, Roundup PowerMax or Gramoxone in a burndown, Sharpen PRE or Bolero delayed-PRE, and Basagran or Loyant (8 or 16 fl oz/ac) POST are the best herbicide options for effectively controlling white-margined flatsedge. RiceBeaux (propanil + thiobencarb) may also be a viable option if densities are low and plants are small as propanil was effective at suppressing emerged plants and the thiobencarb (Bolero) component would add residual to mitigate another flush. As with other weeds, successful management of white-margined flatsedge requires the use of multiple effective herbicide options and applying POST herbicides well-timed when plants are small. Starting out with a clean seedbed, applying an effective residual herbicide, proper weed identification, and following with appropriate POST herbicide selection paired with correct timing are key for season-long control of this new and upcoming problematic weed.

Acknowledgments

Thank you to the Arkansas Rice Research and Promotion Board, University of Arkansas System Division of Agriculture, and Gowan Company for their support of this research. Additionally, thank you to crop consultants Austin Miller and Dustin Engler for providing on-farm field locations for this research.

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Table 1. Herbicide treatments used in each study evaluating white-margined flatsedge control conducted in 2020 in Arkansas.[a]

Trt. no.	Burndown	Rate	Trt. no.	PRE	Rate	Trt. no.	POST	Rate
		(oz/ac)			(oz/ac)			(oz/ac)
1	NTC		1	NTC		1	NTC	
2	2,4-D LV4	32.0	2	Gambit	2.0	2	Grasp	2.0
3	Roundup	32.0	3	Permit Plus	0.8	3	Permit Plus	0.8
4	Gramoxone	64.0	4	Grasp	2.0	4	Newpath	6.0
5	Sharpen	3.0	5	Strada	2.1	5	Gambit	2.0
			6	NTC		6	Loyant	8.0
			7	League	6.4	7	Loyant	16.0
			8	Sharpen	3.0	8	Basagran	32.0
			9	Bolero	64.0	9	Propanil	128.0
			10	Command	15.0	10	Sharpen	1.0
			11	Facet L	43.0	11	Aim	1.3
						12	2,4-D LV4	32.0
						13	Facet L	32.0
						14	Regiment	0.5

[a] An adjuvant was added to herbicides when labels specified the use of one.

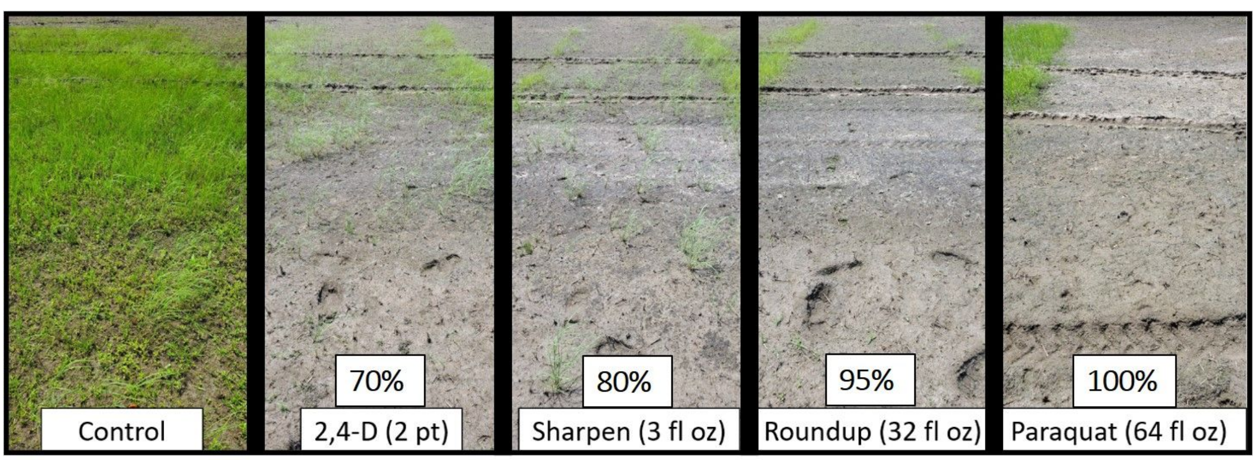

Fig. 1. Observational results of an on-farm demonstration evaluating burndown herbicides for their effectiveness at controlling white-margined flatsedge.

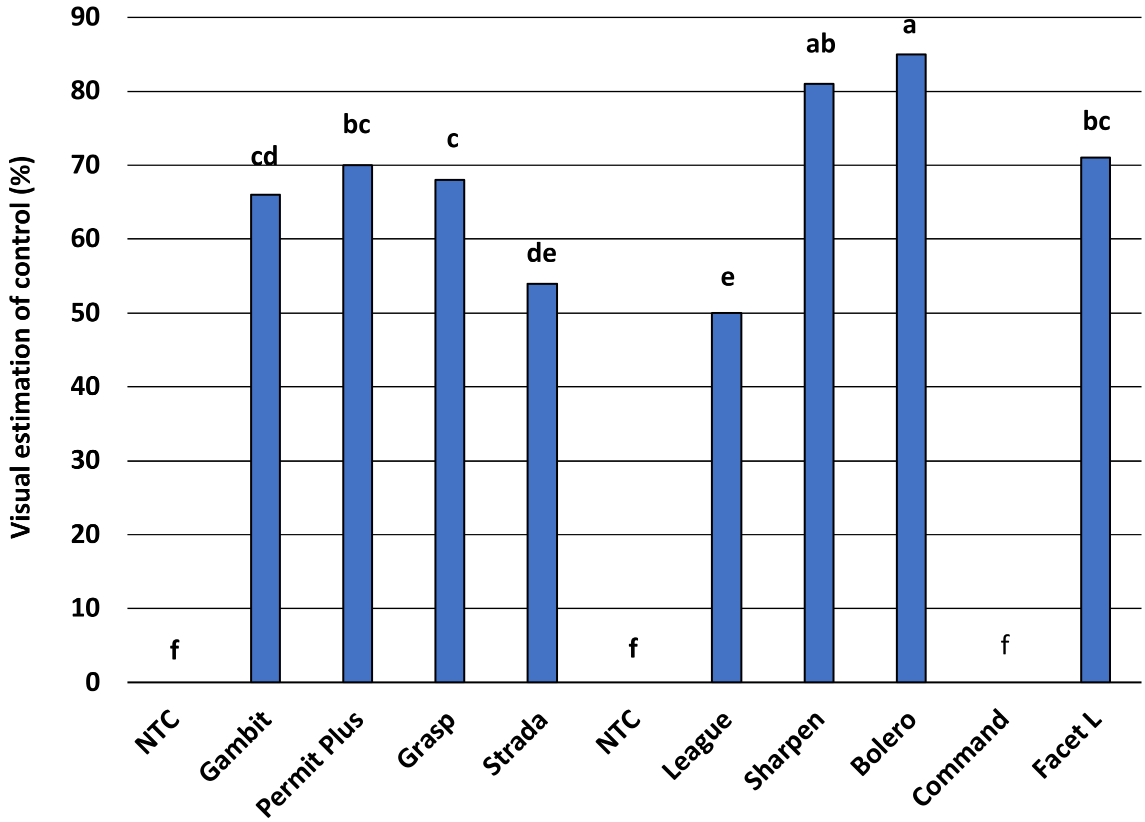

Fig. 2. White-margined flatsedge (*Cyperus flavicomus* Michx.) control at 6 weeks after preemergence (PRE) treatments were applied. Treatments with the same letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

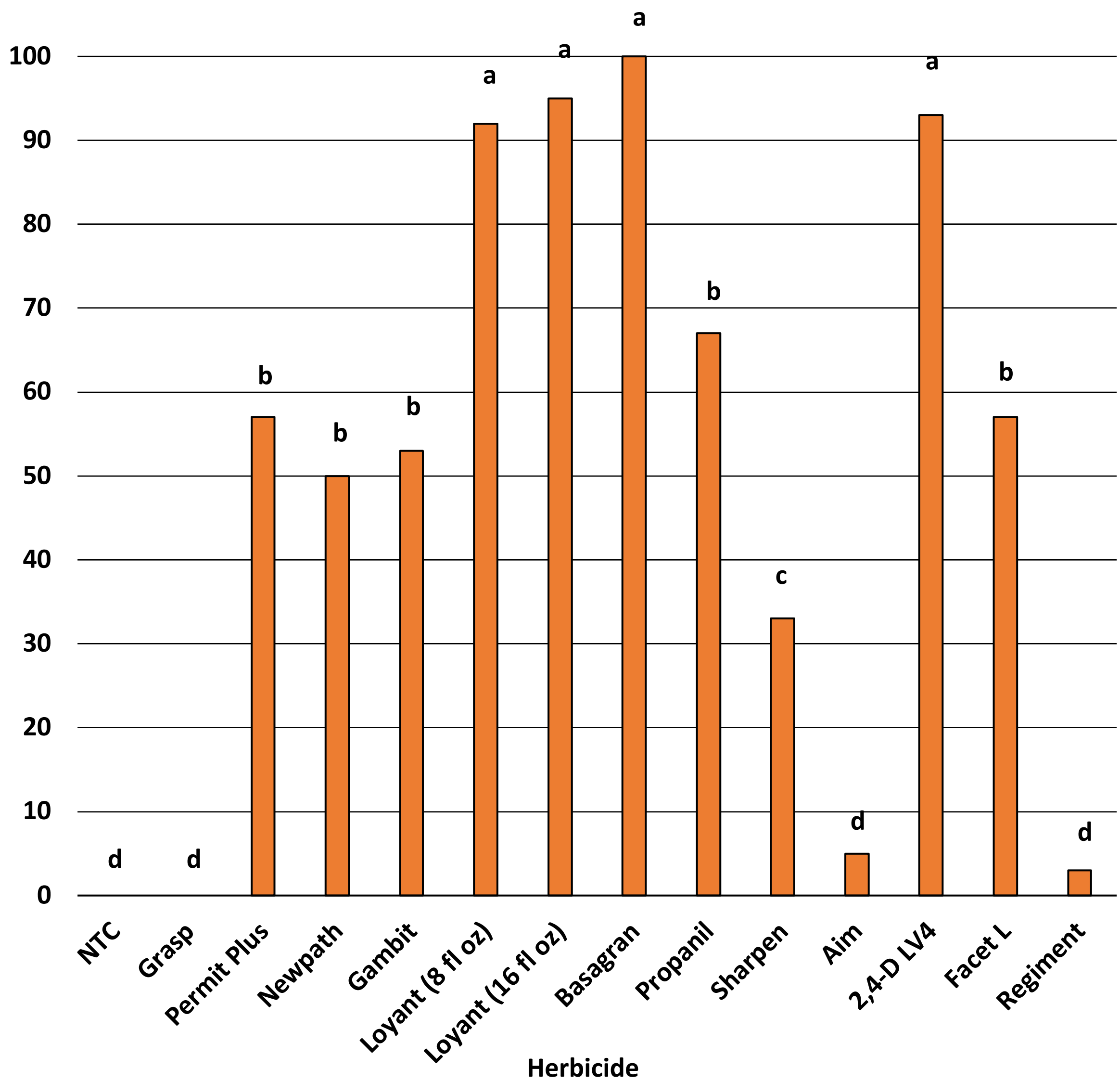

Fig. 3. White-margined flatsedge (*Cyperus flavicomus* Michx.) control 3 weeks after a postemergence (POST) application was applied. Treatments with the same letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

Spray Volume Impact on Droplet Dynamics, Coverage, and Weed Control from Aerial Herbicide Applications

T.R. Butts,[1] L.T. Barber,[1] J.K. Norsworthy,[2] and J. Davis[3]

Abstract

Approximately 51% of Arkansas herbicide applications are made using agricultural aircraft. The optimization of these applications is necessary to maximize weed control and protect crop yields. The objective of this research was to investigate commonly used spray volumes from aerial herbicide applications and determine their effect on droplet size, deposition, coverage, and weed control. A large-scale field study was conducted in 2020 near Jonesboro, Arkansas using an Air Tractor 802A fixed-wing aircraft. Strips consisting of 3 aircraft passes were sprayed to evaluate 3 spray volume treatments (3, 5, and 7 GPA) with 3 replicates. Three water-sensitive cards per replicate were evenly spaced in the center pass of each treatment to assess droplet size, deposition, and spray coverage. Visual estimates of weed control were taken, and an unmanned aerial system (UAS) collected red and near-infrared imagery used to calculate a Normalized Difference Vegetation Index (NDVI) to assess weed control. Results showed the 7 GPA spray volume had greater coverage than 3 GPA but was similar to 5 GPA. Droplet size increased as spray volume increased due to the alterations to other application parameters (increasing nozzle orifice size and pressure) necessary to change spray volume treatments. Barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] control increased as spray volume increased; however, spray volume did not affect rice flatsedge (*Cyperus iria* L.) control. This is likely due to droplet size being the more important driver for controlling a small, vertically oriented weed-like rice flatsedge compared to the broader and more horizontal leaf structure of barnyardgrass. No statistical differences in NDVI measurements from UAS imagery across treatments were observed. As rice flatsedge was the predominant weed species present, UAS data corroborated visual estimates of weed control data. This research provided insights into optimizing herbicide applications from agricultural aircraft to better control weeds.

Introduction

Aerial herbicide applications are critical for successful rice production in Arkansas, and approximately 51% of Arkansas herbicide applications are made using agricultural aircraft (Butts et al., 2021). The optimization of these applications is a necessity to maximize weed control and protect crop yields. Frequently after a weed control failure occurs following an aerial herbicide application, the lack of control is blamed on low spray volumes and reduced coverage. Reductions in airspeed are typically recommended to increase spray volume, increase droplet size, and reduce spray drift from an aerial application (Fritz et al., 2009). However, due to the high payload capacity of today's agricultural aircraft [e.g., the Air Tractor 802A has 59% of maximum take-off weight dedicated to payload (Air Tractor, 2020)], reducing airspeed is difficult and results in dangerous operating conditions. Therefore, increasing spray volume is restricted to changes in nozzle orifice size and spray pressure which have limited ranges in their ability to increase output.

Due to stark differences in the equipment, spray atomization process, and overall spray dynamics between ground and aerial spray equipment, applying recommendations from ground sprayer research to aerial applications is not a viable option. As a result, research directly evaluating aerial application dynamics, specifically regarding commonly used spray volumes is needed. The objective of this research was to investigate the spray volume effect from an aerial herbicide application on droplet dynamics such as size, deposition, and coverage, as well as evaluate the subsequent weed control.

Procedures

A large-scale field study (40 ac) was conducted in the summer of 2020 at the Northeast Rice Research and Extension Center near Jonesboro, Arkansas (35.6517, -90.7195) using an Air Tractor 802A fixed-wing aircraft (Air Tractor, Inc., Olney, Texas 76374) with a 72-ft swath width. The aircraft was equipped with 40° flat fan nozzles (CP Nozzles, Transland, LLC., Wichita Falls, Texas 76302) and operated at a 165-mph airspeed, a 15-ft flight height, and 0° deflection angle across treatments. Strips consisting of 3 aircraft passes (216 x 800 ft) were sprayed to evaluate 3 spray volume treatments (3, 5, and 7 GPA) and were replicated 3 times. Nozzle orifice sizes (1.5, 2.0, and 2.5 GPM) and spray pressures (30, 43, and 60 PSI) were increased to produce the spray volume treatments of 3, 5, and 7 GPA, respectively. A nontreated control strip was also included for comparisons. A tank-mixture of bentazon (Basagran, Winfield Solutions, LLC., St. Paul, Minnesota 55164) and cyhalofop + penoxsulam (RebelEx, Corteva Agri-

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science, Wilmington, Delaware 19805) herbicides was utilized to control the predominant weed species present at the field site: rice flatsedge and barnyardgrass.

Data collection consisted of water sensitive spray cards, visual estimates of weed control, and unmanned aerial system (UAS) imagery collecting red and near-infrared reflectance used to calculate a Normalized Difference Vegetation Index (NDVI). Three water-sensitive spray cards per replicate were evenly spaced in the center pass of each treatment to assess droplet dynamics and spray coverage. Water sensitive spray cards were analyzed using DepositScan from the USDA-ARS Application Technology Unit. Spray classifications were determined and reported using guidelines established in ANSI/ASABE S572.3 (ANSI/ASABE, 2020). Visual estimates of weed control were taken, and a UAS collected NDVI measurements 20 days after application (DAA) to assess weed control. Visual weed control was assessed on a scale of 0 to 100%, where 0 = no control and 100 = complete plant death. A DJI Matrice 210 V2 UAS (SZ DJI Technology Co., Ltd., Shenzhen, China 518057) carrying a MicaSense RedEdge MX camera (MicaSense, Inc., Seattle, Washington 98103) was flown at a height of 200 ft with a ground sample distance of 1.6 in./pixel. The UAS collected images across five discrete wavelength bands: blue (475 nm center, 20 nm bandwidth), green (560 nm center, 20 nm bandwidth), red (668 nm center, 10 nm bandwidth), red edge (717 nm center, 10 nm bandwidth), and near-infrared (NIR, 840 nm center, 40 nm bandwidth). Radiometric calibration (adjustment for solar radiation intensity) and orthorectification of imagery (stitching of images together to resolve pixel distortion) was completed by Pix4D Mapper from Pix4D version 4.5.6. An NDVI layer was calculated using the red and near-IR bands

$$\left[NDVI = \frac{(NIR - red)}{(NIR + red)} \right]$$

and within strip pixel values were averaged and extracted using ArcGIS Pro version 2.7.0 (ESRI Inc., Redlands, California 92373). All data were statistically analyzed using SAS v9.4 and means were separated using Tukey's honestly significant difference test with an $\alpha = 0.05$.

Results and Discussion

Representative samples of water sensitive spray cards from each treatment are shown in Fig. 1. Results from water sensitive spray card data showed that generally, coverage increased as spray volume increased; however, statistically, 7 GPA spray volume had greater coverage than 3 GPA, but similar to 5 GPA (Table 1). An unintended consequence of increasing spray volume was that droplet size ($D_{v0.5}$) increased (150 to 229 µm). The $D_{v0.5}$ is the droplet diameter in which 50% of the spray volume is contained in droplets with a lesser diameter. This increase in droplet size was due to the alterations to other application parameters (increasing nozzle orifice size and spray pressure) necessary to increase spray volume from agricultural aircraft (Bouse, 1994; O'Connor-Marer, 2014). Droplet deposits were equal across spray volume treatments illustrating the interaction between droplet size and spray volume as the smaller droplet size of the 3 GPA treatment was able to compensate for the lower spray volume.

Visual estimates of weed control revealed a unique result from the effect of spray volume on controlling the two dissimilar weed species. Barnyardgrass control numerically increased as spray volume increased, but statistically, 5 GPA and 7 GPA provided equivalent control (Fig. 2). Conversely, spray volume did not affect rice flatsedge control. This was likely due to droplet size being the more important driver for controlling a small, vertically oriented weed such as rice flatsedge compared to the broader and more horizontal leaf structure of barnyardgrass, which could retain greater droplet sizes (Kirk et al., 1989). Data from UAS imagery revealed no statistical differences in NDVI measurements from spray volume treatments (Fig. 3). As rice flatsedge was the predominant weed species present providing the greatest ground cover, this result from NDVI data collected using UAS imagery corroborated visual estimates of weed control data.

Practical Applications

This research provided insights into optimizing herbicide applications from agricultural aircraft to better control weeds and more effectively utilize precision aerial application technologies. The effect of spray volume on weed control from aerial herbicide applications is not as clear cut as previously suspected. Factors such as droplet size, weed size, and weed species structure also play important roles in the final efficacy of our herbicide applications. Further research is needed to evaluate more weed species and herbicide active ingredients to fully understand how spray volumes commonly used by aerial herbicide applications affect rice weed control.

Acknowledgments

Thank you to the Arkansas Rice Research and Promotion Board for partially funding this research through the Arkansas Rice Checkoff Program. Additional support was provided by the University of Arkansas System Division of Agriculture and the Arkansas State Plant Board. Thank you to Darin Walton and Walton AgWings for flying and applying treatments; Drew Ellis and Cole Woolard of Corteva AgriSciences, Poinsett County Agents, Craig Allen and Jeffrey Works, and my weed science team for their assistance with conducting the study. Finally, thanks to Bradley K. Fritz (USDA-ARS, Aerial Application Technology Unit) and Scott Bretthauer (National Agricultural Aviation Association) for their contributions and support in the creation and design of this research.

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Table 1. Droplet size, spray classification, deposits, and coverage data from water sensitive spray cards as affected by spray volume from an aerial herbicide application.†

Spray volume	Droplet size – $D_{v0.5}$‡	Spray classification§	Droplet deposits	Spray coverage
(GPA)	(µm)		(#/cm^2)	(%)
3	150 b	Fine	217 a	5.7 b
5	192 a	Fine	217 a	7.9 ab
7	229 a	Medium	251 a	11.7 a

† Means within a column followed by the same letter are not statistically different at $\alpha = 0.05$.

‡ $D_{v0.5}$ is the droplet diameter in which 50% of the spray volume is contained in droplets with a lesser diameter.

§ Spray classifications determined according to ASABE S572.3.

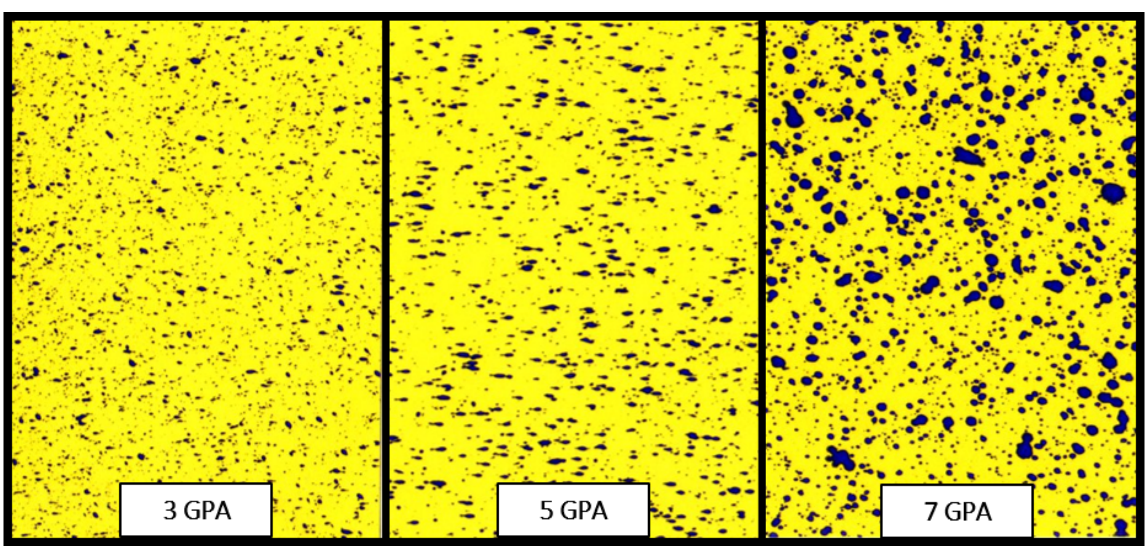

Fig. 1. Water sensitive spray card representative samples evaluating droplet size, deposition, and coverage as affected by spray volume from an aerial herbicide application.

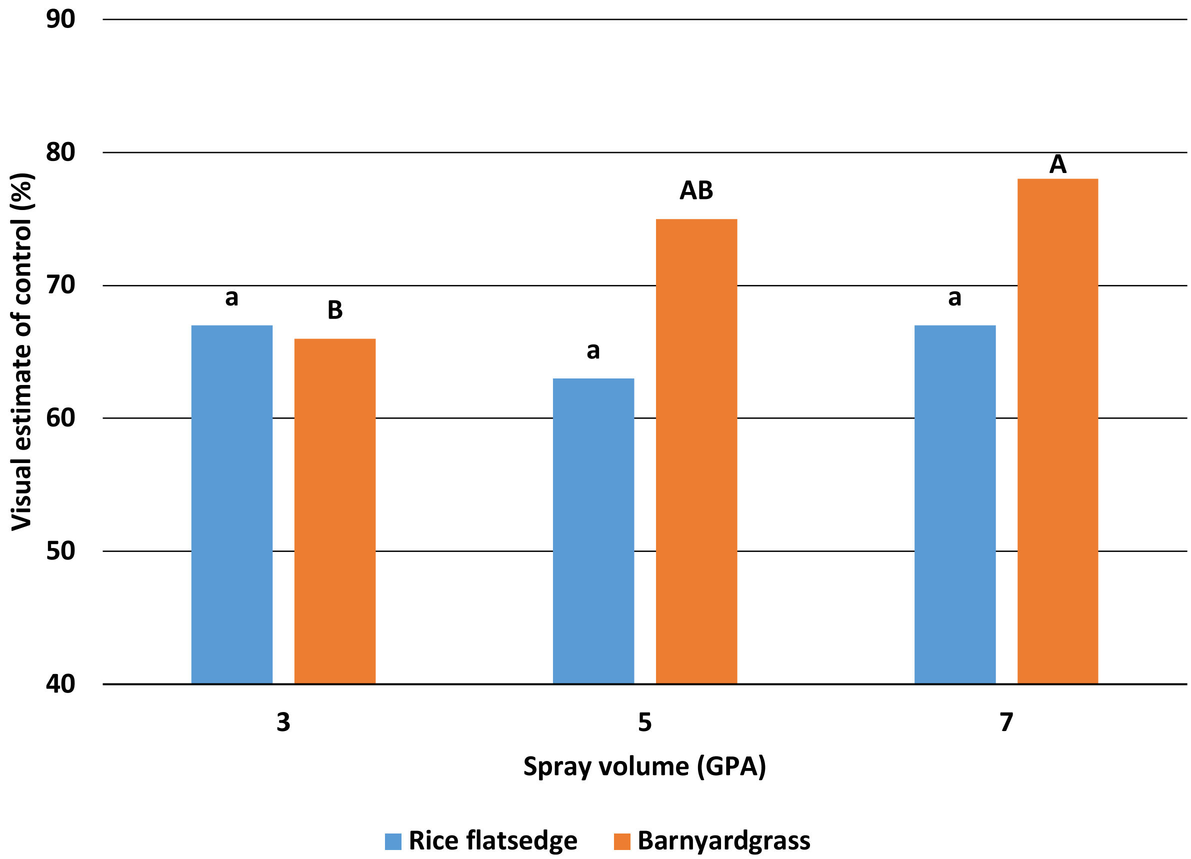

Fig. 2. Visual estimates of rice flatsedge and barnyardgrass control (%) 20 days after application (DAA) as affected by spray volume from an aerial herbicide application. Treatments within weed species with the same lowercase letter (rice flatsedge) or uppercase letter (barnyardgrass) are not different according to Tukey's honestly significant difference test at α = 0.05.

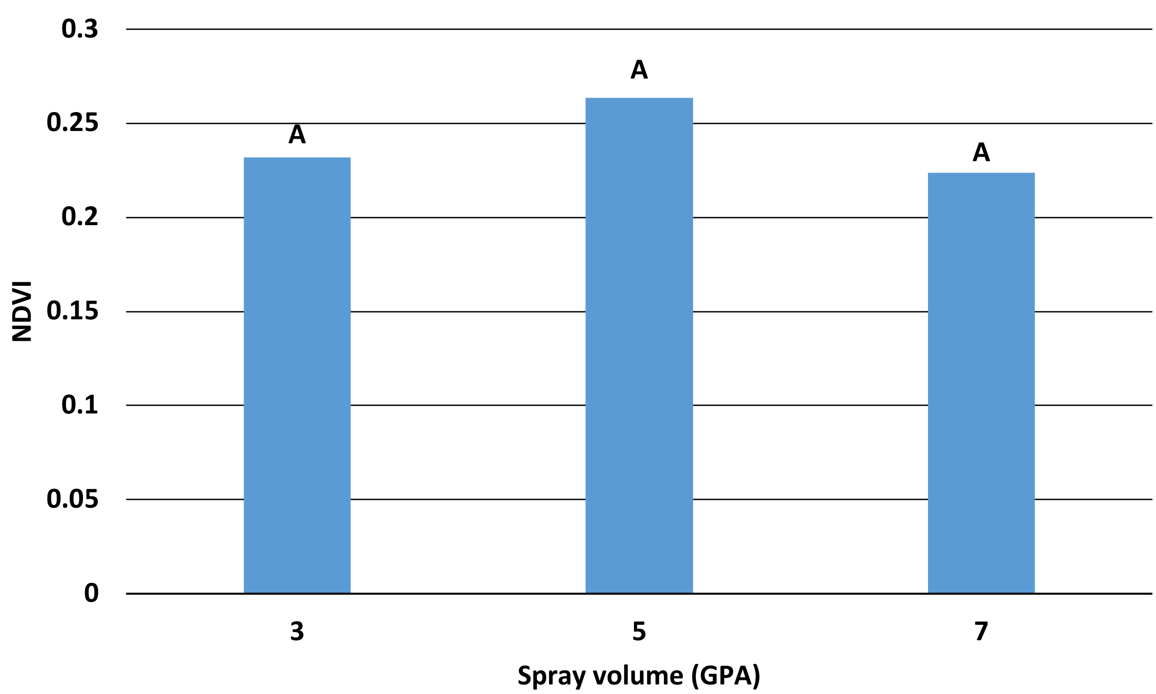

Fig. 3. Normalized Difference Vegetation Index (NDVI) 20 days after application (DAA) as affected by spray volume from an aerial herbicide application. Treatments with the same letter are not different according to Tukey's honestly significant difference test at α = 0.05.

Air Temperature Effect on Barnyardgrass Control from Postemergence Rice Herbicides

L.M. Collie,[1] T.R. Butts,[1] B.M. Davis,[1] L.T. Barber,[1] J.K. Norsworthy,[2] and A. Ellis[3]

Abstract

Arkansas rice producers have noticed a decrease in barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] control when herbicide applications have been made later in the growing season, when greater daytime temperatures are observed, even when all other environmental factors were favorable for herbicide efficacy. The objective of this research was to determine if greater daytime air temperature affects postemergence herbicide efficacy on barnyardgrass. Experiments were conducted at the University of Arkansas at Pine Bluff Small Farm Outreach Center during the 2020 growing season. Herbicide treatments were applied to 3- to 4-leaf barnyardgrass on 27 May at a lower air temperature (daytime high of 79 °F), and the same herbicides were applied on 19 June at a higher air temperature (daytime high of 90 °F) to equivalent-sized barnyardgrass. All herbicides provided 65% or greater control, excluding florpyrauxifen-benzyl (Loyant) alone, 1 week after treatment at the lower temperature (79 °F). However, at the higher temperature (90 °F), barnyardgrass control from cyhalofop (Clincher) and bispyribac-sodium (Regiment) decreased by 30 percentage points or more. Barnyardgrass control from penoxsulam (Grasp) and imazamox (Postscript) were unaffected by air temperature. Overall, barnyardgrass was better controlled when herbicide applications were made with the lower daytime high temperature (79 °F). Applications that are made when the daytime highs are warmer (90 °F) may result in a reduction in the efficacy of some herbicides, and herbicide selection will play a crucial role in maintaining successful barnyardgrass control.

Introduction

Arkansas is the leading rice producer in the United States in terms of acreage planted, acreage harvested, and total production (Hardke, 2019). Changes in the environment, specifically rising temperature and increasing atmospheric carbon dioxide concentration (CO_2), can alter the growth and physiology of weedy plants. These changes could alter herbicide efficacy, crop-weed interaction, and weed management (Refatti et al., 2019). Arkansas rice producers have observed a decrease in barnyardgrass control when herbicide applications are made later in the growing season. The objective of this research was to determine if greater daytime air temperature affects postemergence herbicide efficacy on barnyardgrass.

Procedures

A field study was conducted at the University of Arkansas at Pine Bluff Small Farm Outreach Center near Lonoke, Arkansas, in 2020. Rice cultivar RT 7521 FP was planted at 30 lb/ac on two separate dates to allow for applications to be made to equivalent-sized barnyardgrass and rice but achieve different daytime air temperatures. The experimental design was a randomized complete block with four replications. Treatments consisted of two factors, daytime air temperature [low (79 °F) and high (90 °F)] and herbicide (Table 1). A nontreated control was included for comparisons. Herbicide treatments were applied to 3- to 4-leaf barnyardgrass on 27 May at a lower air temperature (daytime high of 79 °F) and the same herbicides were applied on 19 June at a higher air temperature (daytime high of 90 °F) to equivalent-sized barnyardgrass and rice.

All herbicide applications were made using a pressurized tractor-mounted sprayer equipped with AI110015 nozzles emitting a spray volume of 10 GPA. Visual estimations of weed control were taken 1 and 3 weeks after treatment (WAT). Weed control was defined as percent control, where 0% was no control and 100% was complete control compared to the nontreated control. Data were analyzed and subjected to analysis of variance, and means were separated by Fisher's protected least significant difference test at $\alpha = 0.05$.

Results and Discussion

Weather conditions throughout the duration of this study were consistent and conducive for the evaluation of air temperature on postemergence herbicide efficacy. Barnyardgrass was not drought-stressed, and environmental conditions were similar across application timings except for temperature at application (Figs. 1 and 2). When applications were made at the lower air temperature (79 °F), all herbicides provided 65% or greater control, excluding florpyrauxifen-benzyl (Loyant) alone (55%), 1 WAT (Fig. 3). Efficacy of florpyrauxifen-benzyl was reduced (32.5%) at the higher temperature (90°F) compared to the lower temperature (50%) 3 WAT (Fig. 4). Cyhalofop (Clincher) and bispyribac-sodium (Regiment) provided 60% and 65% control, respectively, when

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applied at the lower temperature 3 WAT, but control dropped to 25% and 20%, respectively, at the higher temperature (Fig. 4). Florpyrauxifen-benzyl + penoxsulam (Novixid) provided 67.5% control 1 WAT, but decreased to 55% control 3 WAT at the lower temperature (Fig. 3 & 4). At the higher temperature, imazamox (Postscript) provided 80% control 3 WAT while all other remaining treatments provided less than 55% control (Fig. 4). Efficacy of penoxsulam (Grasp) and imazamox (Postscript) on barnyardgrass was not affected by the increased daytime air temperature (Figs. 3 and 4).

Practical Applications

Barnyardgrass was controlled more effectively when herbicide applications were made at the lower daytime high temperature (79 °F). If applications are made when air temperature highs are greater (90 °F), producers should expect to see a reduction in the efficacy of some herbicides, and appropriate herbicide selection becomes even more critical to maximize control of barnyardgrass.

Acknowledgments

The authors would like to thank the Arkansas Rice Research and Promotion Board, the University of Arkansas System Division of Agriculture, and Corteva Agriscience for their support of this research.

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Table 1. Herbicide treatments and their corresponding treatment numbers

Treatment Number	Herbicide Treatment	Product Amount
		oz/ac
1	florpurauxifen-benzyl (Loyant)	16.0
2	cyhalofop (Clincher	15.0
3	penoxsulam (Grasp)	2.3
4	florpyrauxifen-benzyl+penoxsulam (Novixid)	27.4
5	bispyribac-sodium (Regiment)	0.6
6	imaxamox (Postscript)	5.0

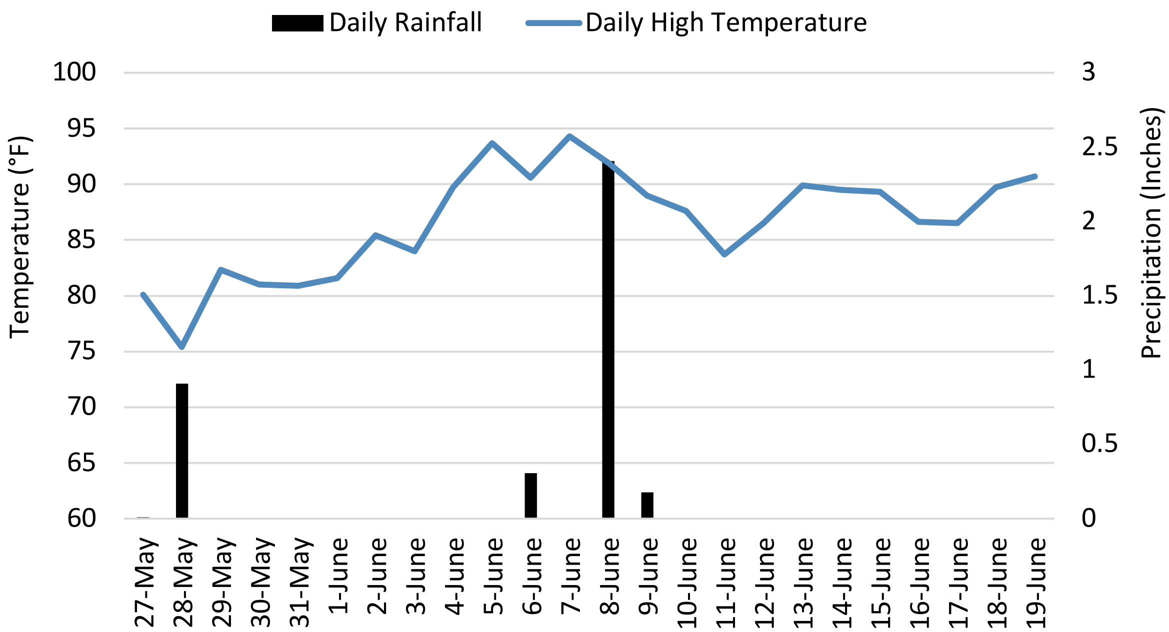

Fig. 1. Daily high temperature and precipitation for the lower temperature application timing (79 °F) from application date to 3 weeks after treatment.

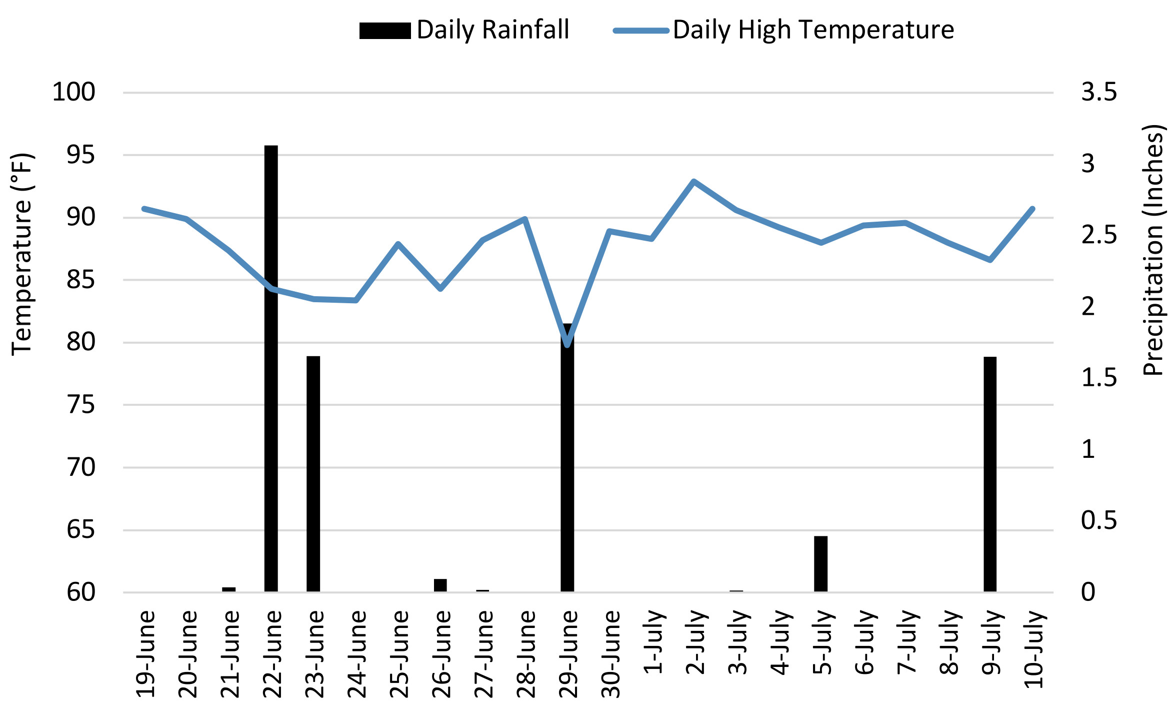

Fig. 2. Daily high temperature and precipitation for the higher temperature application timing (90 °F) from application date to 3 weeks after treatment.

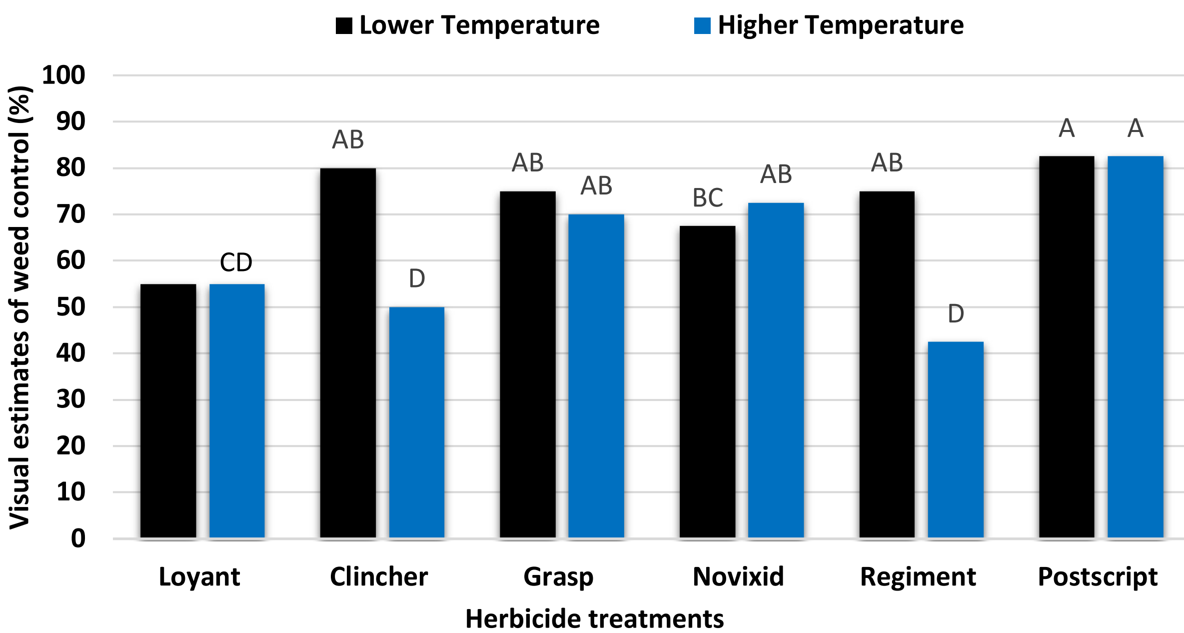

Fig. 3. Visual estimates (%) of barnyardgrass control 1 week after treatment. Treatments with the same letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

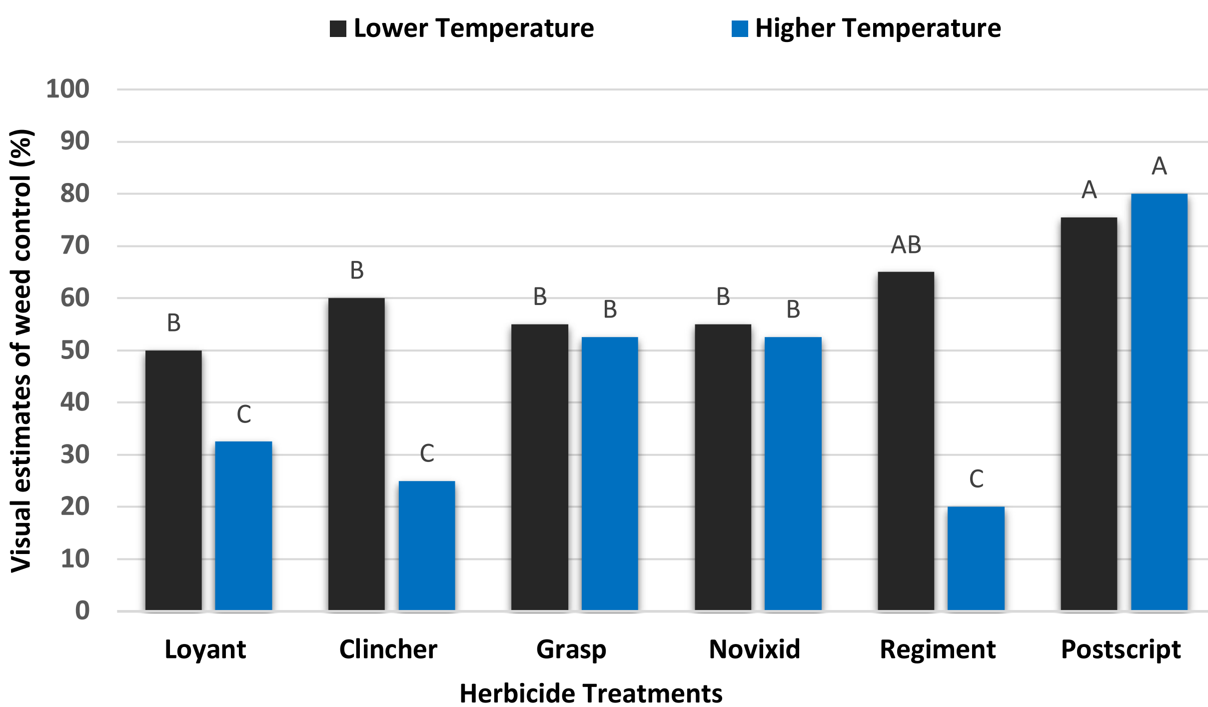

Fig. 4. Visual estimates (%) of barnyardgrass control 3 weeks after treatment. Treatments with the same letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

Florpyrauxifen-benzyl Impregnated on Urea Reduces Risk for Off-target Movement

B.L. Cotter,[1] J.K. Norsworthy,[1] J.W. Beesinger,[1] T.R. Butts,[2] and L.T. Barber[2]

Abstract

Following the commercial launch of Loyant® (florpyrauxifen-benzyl) in 2018, frequent off-target movement of the herbicide to adjacent soybean (*Glycine max*) fields was observed. Hence, field experiments were conducted in 2020 in Fayetteville, AR, to evaluate soybean injury following low rates (0.003 oz ai/ac to 0.094 oz ai/ac) of florpyrauxifen-benzyl applied either as a foliar spray or impregnated on urea at the V3 stage. In two separate field experiments, the response of soybean was evaluated when florpyrauxifen-benzyl was applied in wide-row and narrow-row systems at 7, 14, 21, and 28 days after application. In both experiments, 100% soybean injury (death) occurred following foliar spray applications in both wide- and narrow-row (36-in. and 7-in.) soybean. However, when impregnated on urea, the maximum soybean injury from florpyrauxifen-benzyl at 0.094 oz ai/ac resulted in only 20% and 24% soybean injury in wide- and narrow-row soybean, respectively. At all timings, an equivalent rate of florpyrauxifen-benzyl on urea caused less injury than that of the foliar applications. Overall, florpyrauxifen-benzyl impregnated on urea reduced soybean injury 50 to 91 and 61 to 92 percentage points in wide- and narrow-row soybean, respectively, across all rating dates when compared to foliar applications. Impregnating florpyrauxifen-benzyl onto urea appears to substantially reduce the risk for off-target movement of the herbicide onto soybean, and future research needs to establish the effectiveness of this application technique on weed control.

Introduction

Florpyrauxifen-benzyl is a WSSA group 4 synthetic auxin rice herbicide that was commercially launched in 2018 as Loyant®. As a rice herbicide, florpyrauxifen-benzyl when sprayed at 0.5 oz ai/ac offers greater than 75% control of broadleaf signalgrass (*Urochloa platyphylla*), barnyardgrass (*Echinochloa crus-galli*), Amazon sprangletop (*Leptochloa panicoides*), large crabgrass (*Digitaria sanguinalis*), northern jointvetch (*Aeschynomene virginica*), hemp sesbania (*Sesbania hederacea*), pitted morningglory (*Ipomoea lacunosa*), Palmer amaranth (*Amaranthus palmeri*), yellow nutsedge (*Cyperus esculentus*), rice flatsedge (*Cyperus iria*), and smallflower umbrellasedge (*Cyperus difformis*) (Miller and Norsworthy, 2018a).

As of 2019, soybean and rice are the top 2 agronomic grains harvested in Arkansas (USDA-NASS, 2019). Although florpyrauxifen-benzyl is an effective rice herbicide, there is a potential for off-target movement of the herbicide to adjacent soybean fields. When evaluating multiple crops [soybean, cotton (*Gossypium hirsutum*), corn (*Zea mays*), grain sorghum (*Sorghum bicolor*), and sunflower (*Helianthus annuus*)] to florpyrauxifen-benzyl, it was concluded that soybean exhibited the greatest sensitivity to the herbicide (Miller and Norsworthy, 2018b). In Arkansas, 51% of herbicide applications were reported to be aerial applications, and herbicide drift was identified as a main concern (Butts et al., 2021). To reduce the potential of off-target movement via herbicide drift, impregnating herbicides onto fertilizers may be one possible solution to the problem. In conservation tillage systems, herbicide-impregnated fertilizers can help create a uniform coverage because fertilizer granules can infiltrate a crop canopy and residue more effectively (Kells and Meggett, 1985). However, under application can lead to decreased weed control, and over applications can lead to increased crop injury (Wells and Green, 1991). Due to various risks associated with applications of florpyrauxifen-benzyl, experiments were conducted to determine if impregnating florpyrauxifen-benzyl onto urea would reduce soybean injury from off-target movement and allow for florpyrauxifen-benzyl to be applied without concern of soybean injury linked to an application.

Procedures

Two field experiments evaluating the risk of off-target movement to wide- and narrow-row soybean of florpyrauxifen-benzyl impregnated on urea were conducted in 2020 at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas. Both experiments were conducted as two-factor randomized complete block designs where seven florpyrauxifen-benzyl rates and two application methods were the factors with 4 replications. Credenz soybean variety 4410GTLL was planted on 36-in wide raised beds at a seeding rate of 145,000 seeds/ac, and drilled seeded in a 7-in. wide row at a seeding rate of 152,700 seeds/ac. The center (6 ft) of each plot was treated to prevent contamination from adjacent plots. Foliar-applied florpyrauxifen-benzyl rates of 0, 0.003, 0.006, 0.012, 0.024, 0.047, and 0.094 oz ai/ac were applied to simulate sub-lethal doses that may occur from spray drift. Herbicide-treated urea was weighed at each rate to treat 120 ft^2 of each plot for impregnated applications. Florpyrauxifen-benzyl at 0.5 oz ai/ac was impregnated onto 283 lb/ac of urea, and rates equivalent to foliar applications were measured and applied to compare injury directly from foliar and impregnated applications. Visual injury ratings were recorded at 7, 14, 21, and

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28 days after the application and evaluated using a 0-100 scale, where 0 represents no injury and 100 complete crop death. Grain yield was harvested from the two center rows or center of each plot using a small-plot combine. Grain moisture was adjusted to 13%. All injury data were subjected to regression analysis using a Weibull Growth Model for injury level prediction. All yield data were subjected to regression analysis using an Exponential 2P Model to predict yield.

Results and Discussion

In both wide- and narrow-row soybean experiments, impregnating florpyrauxifen-benzyl on to urea decreased levels of soybean injury (Figs. 1 and 2). At 21 days after treatment and 0.094 oz ai/ac, soybean injury from florpyrauxifen-benzyl impregnated urea only reached approximately 20% and 22% in wide- and narrow-row soybeans, respectively. On the contrary, 100% visual soybean injury was evaluated at 0.094 oz ai/ac in both experiments for the foliar application. Across all rating timings, impregnating florpyrauxifen-benzyl on to urea decreased soybean injury 50 to 91 and 61 to 92 percentage points in wide- and narrow-row soybean, respectively. Impregnating florpyrauxifen-benzyl onto urea caused no effect on yield in both soybean experiments, whereas foliar drift rates had a significant reduction in yield (Figs. 3 and 4). Both experiments resulted in complete soybean yield loss when 0.094 oz ai/ac of florpyrauxifen-benzyl was foliar applied. Impregnating florpyrauxifen-benzyl onto urea appears to be an effective application method to reduce the risk of off-target movement via physical drift.

Practical Applications

Florpyrauxifen-benzyl is currently being applied aerially in limited amounts in Arkansas. Impregnating florpyrauxifen-benzyl onto urea would provide a safer means of herbicide application, as well as potentially decreasing the required number of aerial applications at the pre-flood timing in rice by combining a herbicide and fertilizer application. Urea granules are larger in size and weight than other nitrogen fertilizers available and would be less likely to move off-target from a physical drift occurrence. Florpyrauxifen-benzyl is needed as an additional herbicide option with the increasing amounts of herbicide resistance in rice weeds.

Acknowledgments

This research was conducted in cooperation with Corteva Agriscience Inc. We would like to thank Corteva for partially funding this research and providing the florpyrauxifen-benzyl. Support for this research was also provided by the Arkansas Rice Checkoff Program administered by the Arkansas Rice Research and Promotion Board. Lastly, the facilities were made possible by the University of Arkansas System Division of Agriculture.

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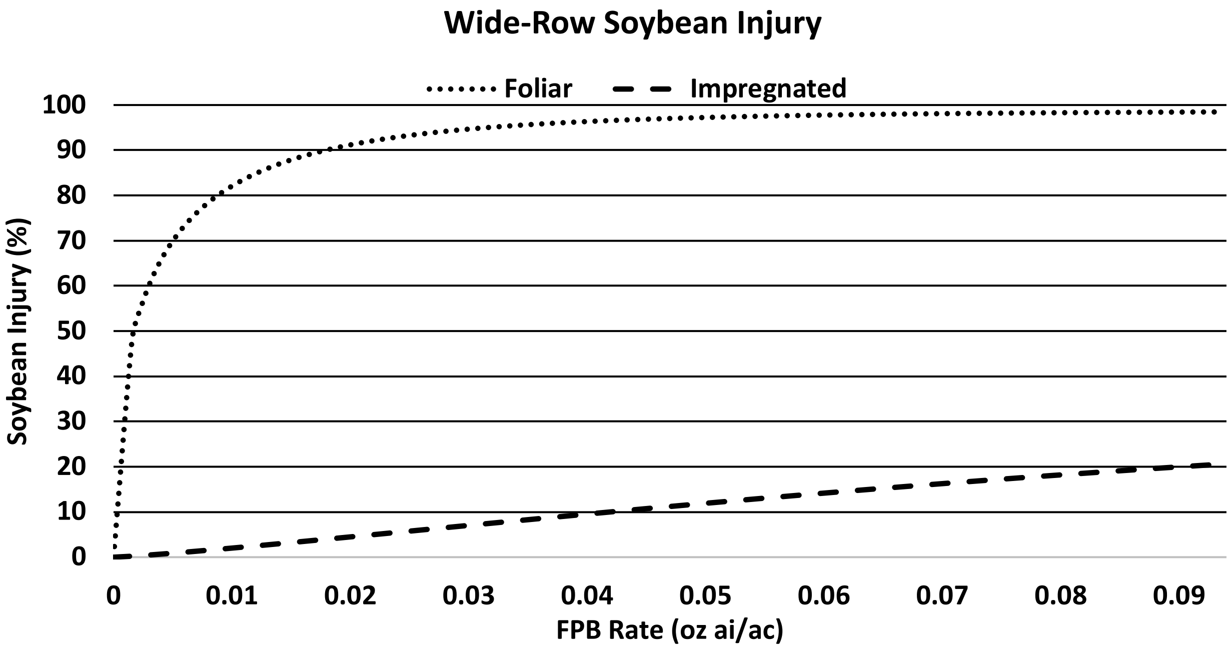

Fig. 1. Weibull growth model, Y = a(1-EXP(-(rate/b)c)), of wide-row soybean visual injury 21 days after treatment of florpyrauxifen-benzyl (FPB) applications. Foliar treatments produced an R^2 = 0.985, and impregnated treatments produced an R^2 = 0.872.

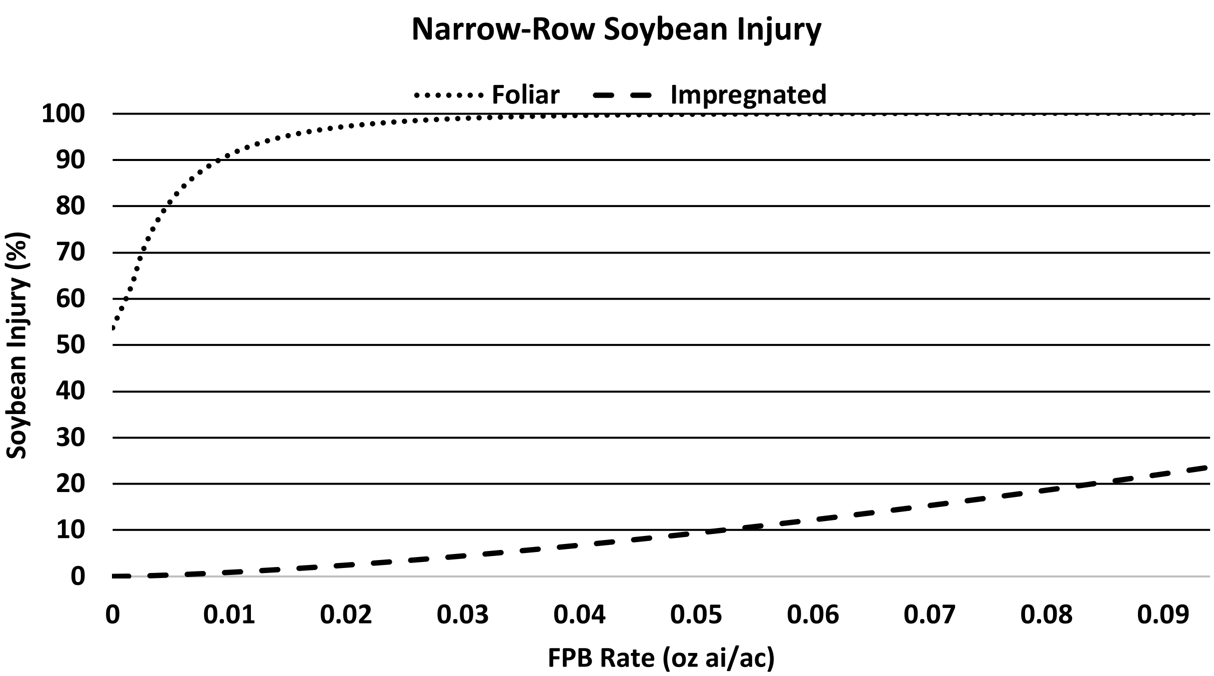

Fig. 2. Weibull growth model, Y = a(1-EXP(-(rate/b)c)), of narrow-row soybean visual injury 21 days after treatment of florpyrauxifen-benzyl (FPB) applications. Foliar treatments produced an R^2 = 0.993, and impregnated treatments produced an R^2 = 0.942.

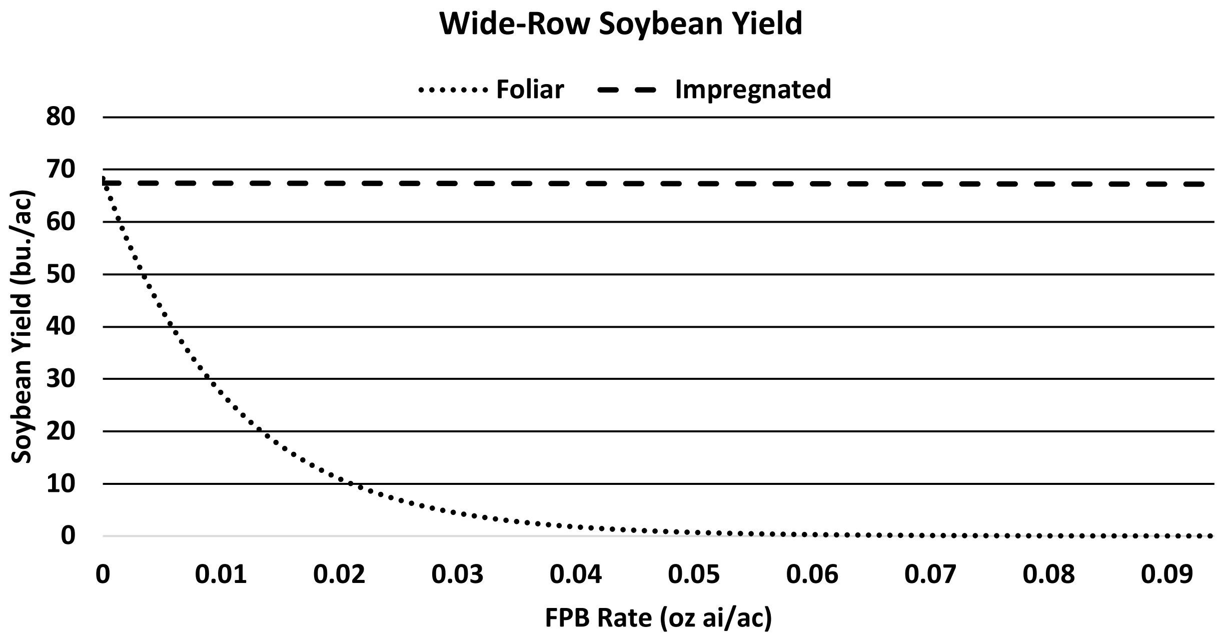

Fig. 3. Exponential 2P model, Y = a(EXP(b*rate)), of wide-row soybean yield. Florpyrauxifen-benzyl (FPB) foliar treatments produced an R^2 = 0.939, and impregnated treatment means were averaged due to no differences.

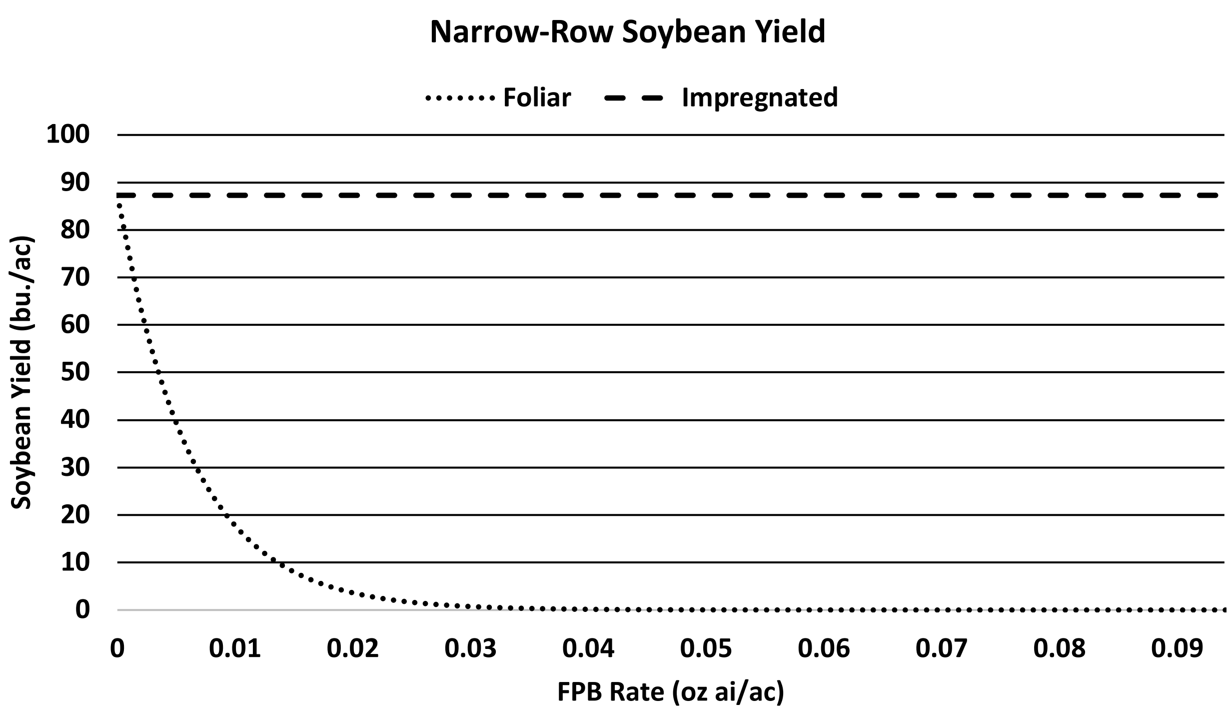

Fig. 4. Exponential 2P model, Y = a(EXP(b*rate)), of wide-row soybean yield. Florpyrauxifen-benzyl (FPB) foliar treatments produced an R^2 = 0.939, and impregnated treatment means were averaged due to no differences.

Herbicide Programs for Combating Weed Species in a Row Rice Production System

B.M. Davis,[1] T.R. Butts,[1] L.M. Collie,[1] L.T. Barber,[1] J.K. Norsworthy,[2] and D. Johnson[3]

Abstract

With groundwater depletion becoming a problem across some rice-producing areas of Arkansas, the need for water conservation and management is key for the long-term outlook of rice. Additionally, tillage and levee formation can be time- consuming and labor-intensive. The use of furrow-irrigated (row) rice can help mitigate water shortages by reducing the total water needed to maintain a flood and minimize the labor and time needed to prepare a field for rice production. However, rice grown without a flood allows for more weeds to germinate until canopy closure, and more atypical rice weeds may be problematic. A study was conducted at the University of Arkansas at Pine Bluff Small Farm Outreach Center near Lonoke to evaluate herbicide programs for row rice on common and atypical Arkansas rice weeds. Nine herbicide program treatments were applied preemergence (PRE), early postemergence at 2- to 3-leaf rice (EPOST), mid-postemergence at 1 tiller rice (MPOST), and late postemergence at 3-tiller rice (LPOST). Results show that the use of preemergence herbicides such as Command (clomazone), Preface (imazethapyr), Obey (clomazone + quinclorac), and others along with timely postemergence applications tank-mixed with another residual herbicide is key for season-long control of both typical and atypical rice weeds. Successful water management is also critical to ensure proper residual activation and maintain appropriate moisture for the success of postemergence herbicides.

Introduction

With an increase of rice (*Oryza sativa* L.) acres planted to row (furrow-irrigated) rice in Arkansas (Hardke, 2019), weed control programs need to be shifted from the conventional paddy rice programs to facilitate weed control without the cultural benefit of a flood. Rice is a unique crop that does not have to be flooded but can withstand growing in flooded conditions. The reason for flooding rice is to achieve weed control on most weeds that cannot grow in flooded conditions. In row rice production, this cultural form of weed control is not present, with watering only occurring when moisture is needed. This, in turn, allows for more atypical weeds to germinate and grow in the rice crop. Therefore, more emphasis and pressure are put on an effective herbicide program to allow the crop time to grow and canopy, thus reducing the ability for weeds to compete (Barber et al., 2020). The objective of this research was to determine successful season-long weed control herbicide programs for row rice on common and atypical Arkansas rice weeds.

Procedures

A study was conducted in the summer of 2020 at the University of Arkansas at Pine Bluff Small Farm Outreach Center near Lonoke, Arkansas. Hybrid rice cultivar RT 7521 FP was drill seeded at 30 lb/ac on 7.5-in. spacings and 30-in. bed widths. The experimental design was a randomized complete block with four replications. Nine herbicide program treatments were applied at preemergence (PRE), early postemergence at 2–3 leaf rice (EPOST), mid-postemergence at 1 tiller rice (MPOST) and late postemergence at 3 tiller rice (LPOST) with a tractor-mounted sprayer equipped with AI 110015 tips calibrated to deliver 10 gal/ac (Table 1). Rice was monitored and managed according to university recommendations regarding fertility and pest control. Row rice was irrigated when needed, usually around every 7 days, unless a rainfall event had occurred. Visual estimations of weed control were taken weekly and were estimated using a scale of 0% to 100%, where 0% is no control and 100% is complete plant death. Yield was taken with a plot combine, and grain moisture was adjusted to 12.5%. Data were subjected to analysis of variance, and means were separated using Fisher's protected least significant difference test at an alpha level of 0.05.

Results and Discussion

At 2 weeks after LPOST, treatments were applied (WALPOST) and prior to harvest (preharvest), barnyardgrass (*Echinochloa crus-galli* P. Beauv.) control was >95% with all herbicide programs (Fig. 1). One key to the season-long control of barnyardgrass was the overlapping of residuals and the reactivation of these residuals. The use of Obey (clomazone + quinclorac) or Command (clomazone) PRE followed by a second application of Command or Preface (imazethapyr) exhibited great season-long control. Rice flatsedge (*Cyperus iria* L.) control 2 WALPOST was >90% for all herbicide programs excluding Treatment 8, which only provided 80% control (Fig. 2). Hemp sesbania [*Sesbania herbacea* (Mill.) McVaugh] at 2 WALPOST was controlled >98% with all programs. Prior to harvest, hemp sesbania control was reduced to 85% in herbicide program treatments that relied solely on an MPOST application of Loyant (florpyrauxifen-benzyl) for broadleaf weed management (Fig. 3). Broadleaf weed control was similar to the principle used for grass control with the use of Sharpen (saflufenacil) PRE to stop emergence or at least reduce

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the number of broadleaf weeds, then following with an application of another broadleaf herbicide such as propanil, Aim (carfentrazone), or Gambit (halosulfuron + prosulfuron) early to MPOST. A herbicide such as Loyant LPOST to control any escaped broadleaf weeds can be used to provide a clean field through harvest. Yields ranged from 173 to 215 bu./ac, but no statistical differences among herbicide programs were observed (Fig. 4). Some atypical rice paddy weeds present, but not in populations conducive for control ratings, were cutleaf groundcherry (*Physalis angulata* L.), sicklepod [*Senna obtusifolia* (L.) H.S. Irwin & Barneby], carpetweed (*Mollugo verticillata* L.), and gooseweed (*Sphenoclea zeylanica* Gaertn.). Herbicide treatments containing synthetic auxin or acetolactate synthase-inhibiting (halosulfuron + prosulfuron, Gambit) herbicides exhibited control of these atypical weeds.

Practical Applications

Initial findings in this study suggest that growers should target weeds, common or atypical, early when small, and apply preemergence herbicides with overlapping residual herbicides to have a successful season-long weed control program in the absence of a permanent flood. Timely application when weeds are small are crucial for a successful program and additional herbicide applications compared to paddy rice may be needed to maintain a season long weed-free crop. With the multiple applications needed, tank mixes with multiple modes of actions along with overlapping of residual herbicides can be key to this success. Water management is also extremely important for the proper activation of residual herbicides and to provide enough moisture for successful POST herbicide control. If there is not a rainfall event within a reasonable amount of time around a herbicide application, an irrigation event will be necessary for good activation.

Acknowledgments

The authors would like to thank the Arkansas Rice Research and Promotion Board, the University of Arkansas System Division of Agriculture, and FMC for their support of this research.

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Table 1. Herbicide programs evaluated for weed control in a furrow-irrigated (row) rice system.[a,b]

Trt. No.	Treatment Name	oz/ac lb/ac	Timing	Trt. No.	Treatment Name	oz/ac lb/ac	Timing
1	Nontreated control			6	Obey	31.0	PRE
2	Command	12.8	PRE		Sharpen	3.0	PRE
	Sharpen	3.0	PRE		Ricebeaux	96.0	EPOST
	Clearpath	0.5	EPOST		Ricestar	24.0	MPOST
	Preface	5.0	MPOST		Loyant	8.0	MPOST
	Regiment	0.4	MPOST		Loyant	8.0	LPOST
	Aim	1.3	MPOST	7	Command	12.8	PRE
3	Command	12.8	PRE		Sharpen	3.0	PRE
	Sharpen	3.0	PRE		Command	12.8	MPOST
	Command	12.8	EPOST		Ricebeaux	96.0	MPOST
	Preface	5.0	EPOST		Ricestar	24.0	LPOST
	Preface	5.0	MPOST		Loyant	8.0	LPOST
	Loyant	8.0	LPOST	8	Command	12.8	PRE
4	Obey	31.0	PRE		Sharpen	3.0	PRE
	Sharpen	3.0	PRE		Obey	38.5	EPOST
	Preface	5.0	EPOST		Ricestar	24.0	LPOST
	Command	12.8	MPOST		Loyant	8.0	LPOST
	Preface	5.0	MPOST	9	Command	12.8	PRE
	Aim	1.3	MPOST		Sharpen	3.0	PRE
5	Command	12.8	PRE		Ricebeaux	96.0	EPOST
	Sharpen	3.0	PRE		Command	17.0	MPOST
	Obey	38.5	EPOST		Permit	1.0	MPOST
	Loyant	8.0	MPOST		Ricestar	24.0	LPOST
	Loyant	8.0	LPOST		Loyant	8.0	LPOST
	Regiment	0.4	LPOST	10	Command	12.8	PRE
					Sharpen	3.0	PRE
					Prowl H20	33.6	EPOST
					Bolero	64.0	EPOST
					Preface	5.0	MPOST
					Gambit	1.5	MPOST
					Clincher	15.0	LPOST

[a] A surfactant was used in all treatments where labels dictated.

[b] Not all tank-mixtures used were labeled but were included for research purposes.

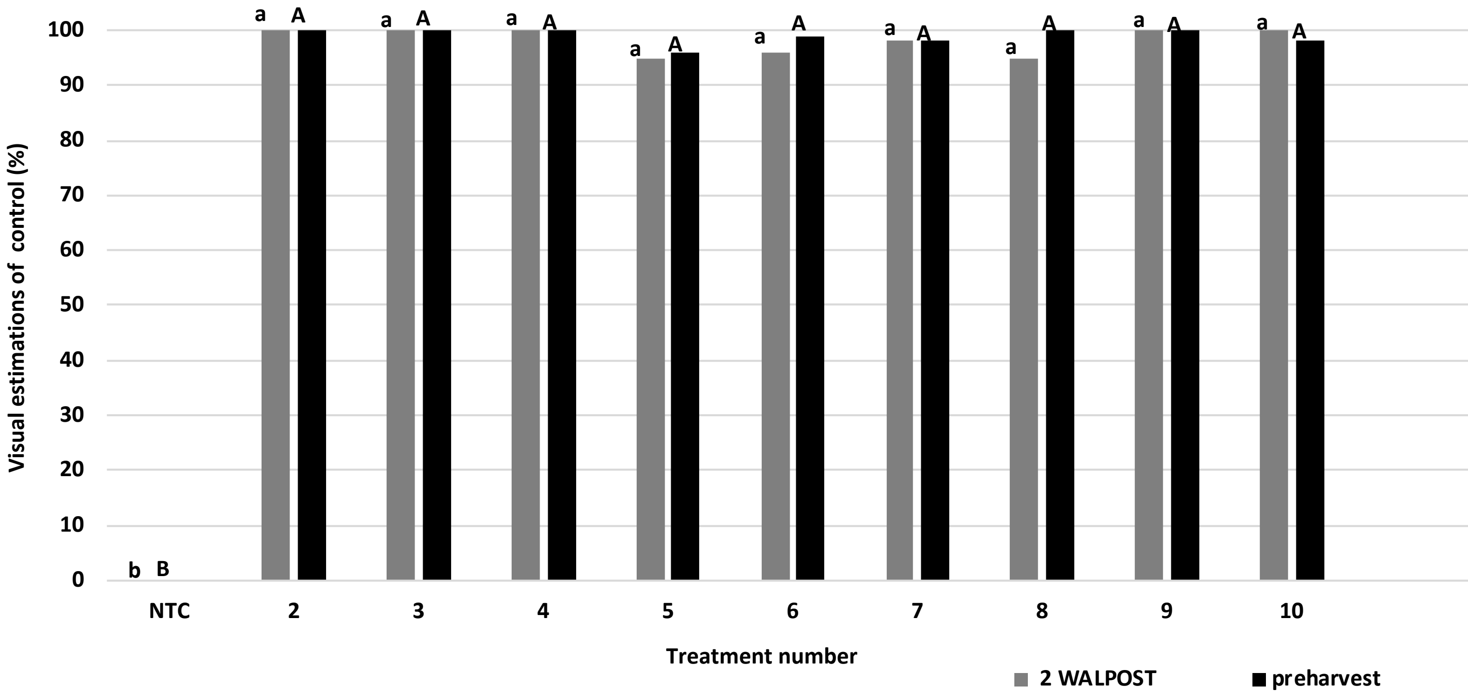

Fig. 1. Barnyardgrass (*Echinochloa crus-galli*) control at 2 weeks after late POST (WALPOST) and preharvest rating timings. Treatments within rating timing depicted with the same letter are not different according to Fisher's protected least significant difference test at α = 0.05. NTC = nontreated control.

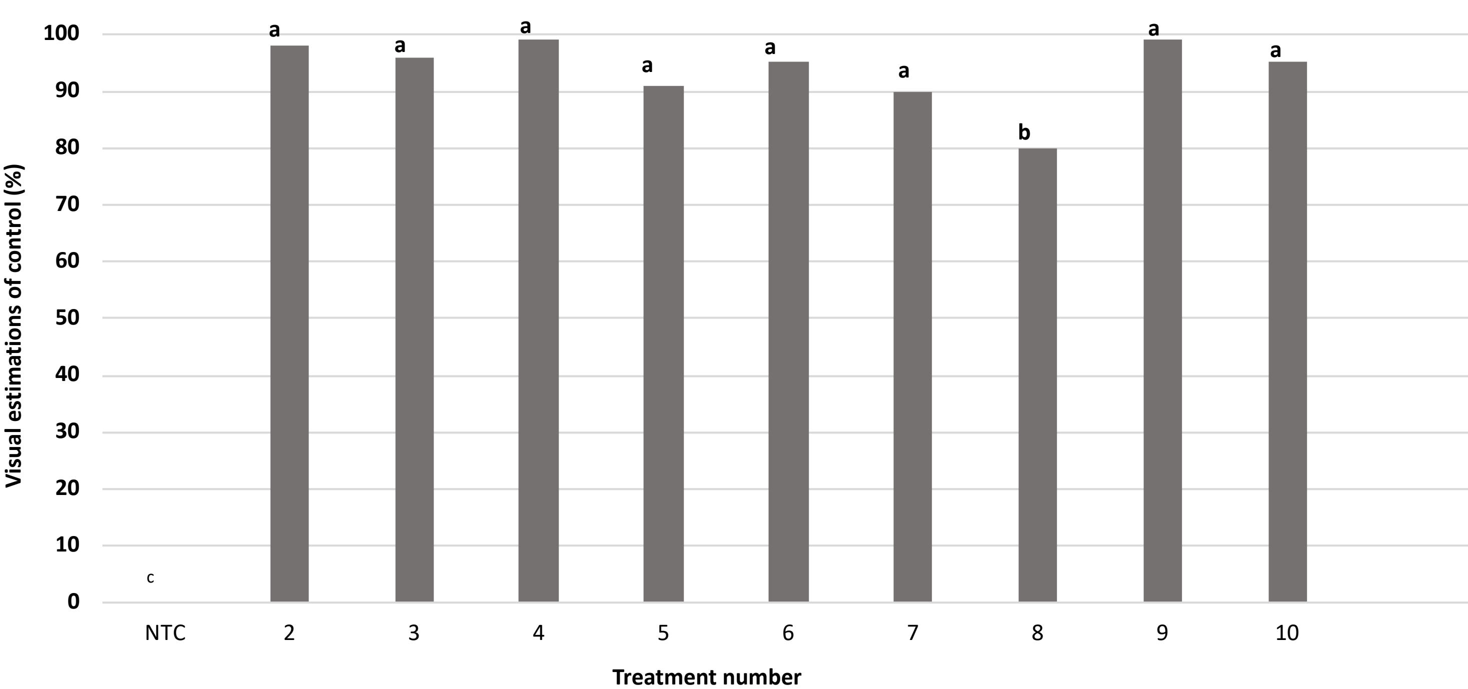

Fig. 2. Rice flatsedge (*Cyperus iria*) control at 2 weeks after late POST (WALPOST) rating timing. Treatments depicted with the same letter are not different according to Fisher's protected least significant difference test at α = 0.05. NTC = nontreated control.

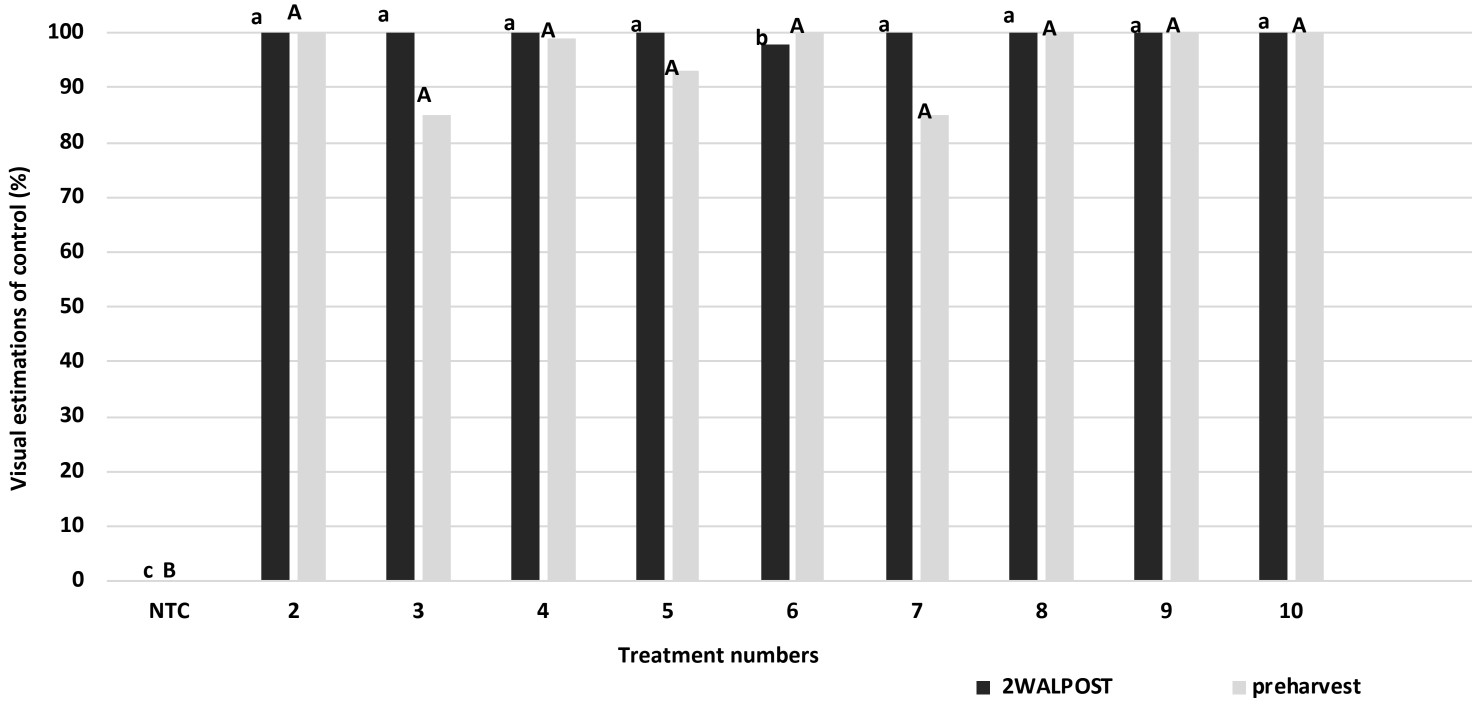

Fig. 3. Hemp sesbania (*Sesbania herbacea*) control at 2 weeks after late POST (WALPOST) and preharvest rating timing. Treatments within rating timing depicted with the same letter are not different according to Fisher's protected least significant difference test at α = 0.05. NTC = nontreated control.

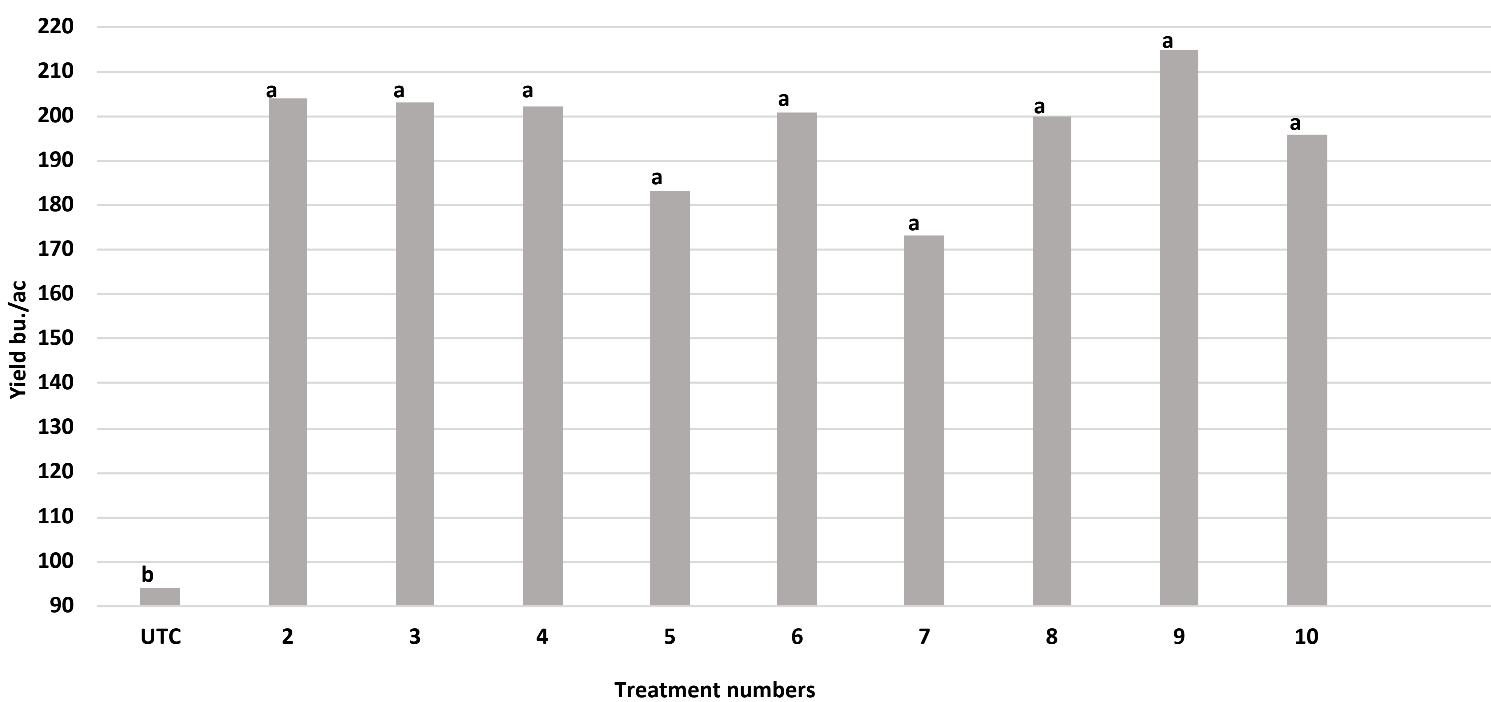

Fig. 4. Rough rice yields in bushels per acre. Treatments depicted with the same letter are not different according to Fisher's protected least significant difference test at α = 0.05. UTC = untreated control.

Tolerance of Acetyl CoA Carboxylase (ACCase)-resistant Rice to Quizalofop

N. Godara,[1] J.K. Norsworthy,[1] L.T. Barber,[2] T.R. Butts,[2] L. Piveta,[1] and M. Houston[1]

Abstract

Quizalofop-resistant rice technology was commercially available for growers in 2018. Shortly thereafter, injury to quizalofop-resistant cultivars was reported following postemergence applications of quizalofop herbicide. A field experiment was conducted in 2020 at the Rice Research and Extension Center, Stuttgart, Arkansas, to determine the level of injury caused by sequential applications of quizalofop at 15.5 fl oz/ac (1X) and 31 fl oz/ac (2X) to PVL01, PVL02, and RTV 7231 (Max-Ace, not commercialized) cultivars that were planted in early April and mid-May. The experiment was implemented as a randomized complete block design with a split-plot arrangement and was replicated four times. Sequential applications of quizalofop were applied at the 2-leaf stage, followed by a second application at the 5-leaf stage before flooding. At 21 days after the second application (DAB), there were no significant injury differences among treatments other than the RTV 7231 cultivar, which had 40% more injury at the higher dosage of quizalofop, averaged over planting dates. The cultivar RTV 7231 showed 30% less ground cover at 1x rate of sequential applications compared with PVL01 and PVL02. Even though higher injury and less ground cover following treatment occurred for RTV 7231, it still showed a higher overall yield potential compared to PVL01 and PVL02 cultivars following a sequential 1x rate. The cultivars PVL01 and PVL02 showed less sensitivity to quizalofop compared to RTV 7231, but they were not able to show as high of yield potential as RTV 7231. Overall, growers can expect to see injury from sequential applications of quizalofop in quizalofop-resistant cultivars.

Introduction

Provisia rice was commercially launched by BASF Corporation in 2018 as a complement to the existing Clearfield technology (Hines 2018). The Provisia rice system is a non-transgenic herbicide-resistant technology that allows for postemergence applications of quizalofop, an acetyl coenzyme a carboxylase (ACCase)-inhibiting herbicide (Guice et al., 2015). Sequential applications of quizalofop at the 1- to 2-leaf stage followed by a second application at the 4- to 5-leaf stage before flooding provides postemergence control of acetolactate synthase (ALS)-resistant grasses, mainly barnyardgrass (Echinochloa crus-galli (L.) Beauv.) and weedy rice (*Oryza sativa* L.) (Barber et al., 2020). RiceTec is also working toward the commercialization of an additional ACCase-resistant rice, with a proprietary quizalofop herbicide being supplied by ADAMA. Previous research reported that quizalofop caused up to 38% injury on quizalofop-resistant rice, but plants generally recovered from injury at later stages (Camacho et al., 2020).

In 2019, several commercial fields of quizalofop-resistant rice (PVL01) in Arkansas were injured following an application of quizalofop. Therefore, it was hypothesized that the inconsistencies among the quizalofop-resistant rice fields in regards to tolerance may be associated with environmental conditions at or near application. The objective of this research was to understand the response of quizalofop-resistant cultivars to sequential applications of quizalofop herbicide over a range of planting dates to produce distinct environments at application.

Procedures

A field experiment was conducted at the Rice Research and Extension Center near Stuttgart, Arkansas, in summer of 2020. The experiment was implemented as a split-plot randomized complete block design and replicated four times. The whole plot factor was planting date (mid-April, early May), and the sub-plot factors were cultivar (PVL01, PVL02, and RTV 7231) and rate of quizalofop-sequential application (0, 1x, and 2x). The field was separated into two different bays according to planting dates, and cultivars were planted into 6 by 17 ft plots at a depth of 0.5-in. with a seeding rate of 22 seeds per ft of drilled row. Sequential applications of Provisia (quizalofop) were made at the 2-leaf rice and 5-leaf rice stage before flooding. Provisia herbicide was applied sequentially at 15.5 fl oz/ac (1x) and 31 fl oz/ac (2x) using a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/ac at 3 mph with AIXR110015 spray nozzles.

Data collected consisted of visible crop injury, rice ground cover, 50% heading dates, and rough rice grain yield. Visible estimations of injury were rated on a 0 to 100 scale, with 0 being no injury and 100 being crop death. Ratings were taken 7 days after the 2-leaf stage application (DAA) and every 7 days after the 5-leaf stage application (DAB). Drone images were taken throughout the crop season and subjected to Field Analyzer software to estimate the relative ground cover. The day when rice reached 50% heading was recorded by plot. Plots were harvested for yield using a small-plot combine, and rough rice grain yield was adjusted to 12% moisture. All data were analyzed by using JMP Pro 15 and

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subjected to analysis of variance. All means were separated using Fisher's protected least significant difference test ($\alpha = 0.05$).

Results and Discussion

Planting date did not influence the response of the quizalofop-resistant cultivars to sequential quizalofop applications. There were no injury symptoms observed across quizalofop-resistant cultivars at the 1x rate of quizalofop following sequential applications other than RTV 7231, which exhibited up to 31% injury at 21 days after second application (DAB), averaged over planting dates (Table 1). At the 2x rate, injury to RTV 7231 increased up to 73% while PVL01 and PVL02 showed ≤22% injury (Table 1). RTV 7231 ground cover was reduced by more than 30% as compared to PVL01 and PVL02 at a 1x rate. At the 2x rate, the ground cover of RTV 7231 was reduced to 17% compared to the nontreated control. There was no significant heading delay observed in any of the quizalofop-resistant cultivars at the 1x rate of sequential applications. RTV 7231 showed a delay of 5 days in heading when quizalofop sequential applications were made at the 2x rate (Table 1). Furthermore, no significant yield losses were observed in the quizalofop-resistant cultivars at the 1x rate. However, RTV 7231 yielded 212 bu./ac as compared to PVL01 and PVL02 at 132 and 123 bu./ac, respectively, following a sequential 1x rate of quizalofop (Table 2).

Practical Applications

Quizalofop-resistant rice technology is an effective tool for Midsouth rice producers. The research showed that regardless of the sensitivity of quizalofop-resistant cultivars to quizalofop, recovery from injury occurred with no impact on yield potential in these trials when applied at a 1X rate.

Acknowledgments

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Table 1. Injury percent and relative ground cover percent at 21 days after a second application (DAB) and relative heading compared to nontreated after sequential quizalofop applications averaged over planting dates.†

Cultivar	Rate‡	Injury	Relative ground cover	Delay in heading
	fl oz/ac	%	%	days
RTV 7231	15.5 fb 15.5	31 b	70 b	1 b
	31 fb 31	73 a	17 c	5 a
PVL01	15.5 fb 15.5	1 d	112 a	1 b
	31 fb 31	12 cd	102 a	1 b
PVL02	15.5 fb 15.5	0 d	102 a	0 b
	31 fb 31	22 bc	63 b	2 b

† Means followed by the same letters within the same column are not significantly different based on Fisher's protected least significant difference with $\alpha = 0.05$.

‡ Abbreviations: fb = followed by.

Table 2. Yield of quizalofop-resistant rice cultivars after sequential applications of quizalofop averaged over planting dates.

	Yield†		
Herbicide‡	**RTV 7231**	**PVL01**	**PVL02**
	------------bu./ac------------		
nontreated	228 a	138 b	114 b
15.5 fb 15.5 fl oz/ac	212 a	132 b	123 b
31 fb 31 fl oz/ac	142 b	137 b	127 b

† Means followed by the same letter are not statistically different at $\alpha = 0.05$.
‡ Abbreviations: fb = followed by.

Sequencing of the Acetyl CoA Carboxylase (ACCase) Gene in Resistant Barnyardgrass (*Echinochloa crus-galli*) Populations

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Abstract

Barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] is globally considered the most troublesome weed of rice (*Oryza sativa* L.) production systems. Several barnyardgrass accessions have evolved resistance to many herbicides with different sites of action. In the U.S., accessions with low susceptibility to PSII-inhibitors, synthetic auxins, acetyl CoA carboxylase (ACCase)-inhibitors, lipid inhibitors, ALS-inhibitors, DOXP-inhibitors, and cellulose inhibiting-herbicides have been reported. The goal of this research was to describe the presence of target site mutations in two ACCase-resistant barnyardgrass accessions collected in Arkansas. For that purpose, genomic DNA was extracted from resistant (R1 and R2) and susceptible (S) accessions. A set of primers were designed to amplify 1.6 kb of the *ACCase* gene. Polymerase chain reaction (PCR) and gel electrophoresis were carried out following standard protocols, and samples were purified and sequenced accordingly. Comparison of the nucleotides and their predictive protein among accessions displayed no amino acid substitution in any of the positions reported previously or in the rest of the sequences obtained. In the accessions analyzed, results showed that target site mutations are unlikely to be involved in resistance to several ACCase-inhibiting herbicides, suggesting the presence of non-target site resistance mechanisms.

Introduction

Rice represents one of the major crops worldwide (Gaikwad et al., 2020). Rice production systems face many agronomic issues, such as the presence of weeds. Among those weeds, barnyardgrass is considered a worldwide problematic weed species. Barnyardgrass is a C_4 plant species with an annual life cycle and a great ability to grow under harsh weather conditions (Juliano et al., 2010; Rao et al., 2007). This weed species is able to produce large amounts of seeds, which may possess dormancy (Gibson et al., 2002). All of those characteristics have made barnyardgrass a very troublesome weed species not only in rice but also in other cropping systems (Clay et al., 2005). Barnyardgrass in rice can cause from 30% to complete crop yield loss if not managed properly (Miller et al., 2015). Management of barnyardgrass in rice relies mostly on the use of herbicides, and unfortunately, many accessions have been reported as herbicide-resistant to different sites of action. In the U.S., accessions resistant to PSII-inhibitors, synthetic auxins, ACCase-inhibitors, lipid inhibitors, ALS-inhibitors, DOXP-inhibitors, and cellulose inhibiting-herbicides have been reported (Heap, 2021).

Acetyl CoA carboxylase-inhibiting herbicides work by stopping the biosynthesis of fatty acids, which prevents the formation of lipids and other metabolites. As a consequence, cells are disrupted and finally leads to cell death (Délye et al., 2005). Acetyl CoA carboxylase-inhibiting herbicides are classified into three groups: aryloxyphenoxypropionates (commonly referred to as FOPs), cyclohexanediones (commonly referred to as DIMs), and phenylpyrazolin (known as DEN) (Délye et al., 2005; Hofer et al., 2006).

The objective of this study was to describe the presence of single nucleotide polymorphisms (SNPs) previously reported in conferring resistance to ACCase-inhibiting herbicides in two barnyardgrass accessions with reduced sensitivity to cyhalofop herbicide.

Procedures

Research to determine the presence of SNPs in the *ACCase* gene was conducted in the facilities of the University of Arkansas System Division of Agriculture's Don Tyson Center for Agricultural Sciences, Fayetteville, Arkansas. Preliminary results showed a differential susceptibility to cyhalofop herbicide in two barnyardgrass accessions (hereafter named as R1 and R2) when compared to a susceptible (S) one (Fig. 1). Young leaf tissue of R1, R2, and S accessions was collected, placed in Eppendorf tubes, and maintained at -80 °C until DNA extraction. Genomic DNA (gDNA) was isolated from leaf tissue by using the E.Z.N.A. Plant DNA kit (Omega Bio-Tek, Ga., USA) and quantified spectrophotometrically (Nanodrop 2000c, Thermo Scientific, Mass., USA). A forward and a reverse primer were designed using a published ACCase-inhibitor-susceptible barnyardgrass' sequence. Both primers were designed using the free available Primer3 software and produced an amplicon of 1.6 kb. Standard PCR reactions were carried out as described by Brabham et al., (2020). Cycling conditions were as follows: 94 °C for 2 min; 35 cycles with a denaturation at 94 °C for 30 s; annealing at 63 °C for 30 s; an extension of 72 °C for 1:30 min, and finally, 5 min at 72 °C. After PCR cycling, an aliquot was run on a 1.5% w/v agarose gel to corroborate appropriate amplification. Then, the rest

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of the PCR products were cleaned and sent for Sanger sequencing. Sequences were analyzed by using BioEdit (Hall, 1999) and Multalin (Corpet, 1988) software. At least three biological samples of each accession in both senses were sequenced.

Results and Discussion

A 1.6 kb fragment of the *ACCase* gene from resistant and susceptible barnyardgrass accessions was sequenced. The nucleotide sequences and the predicted proteins were searched using the Basic Local Alignment Search Tool (BLASTn and BLASTp algorithms respectively), available at https://blast.ncbi.nlm.nih.gov/Blast.cgi. Nucleotide sequence searching displayed almost 100% homology with the acetyl-CoA carboxylase sequences of barnyardgass (GenBank accession HQ395758.1) and *E. phyllopogon* (GenBank accession AB636586.1). In addition, the predictive proteins showed a high homology (99%) with barnyardgrass (GenBank accession ADR32358.1) and junglerice (GenBank accession APZ87886.1) acetyl-CoA carboxylase proteins.

Sequence comparison among the R1, R2, and S barnyardgrass accessions displayed no SNPs in any position reported previously in conferring resistance to ACCase inhibiting-herbicides or in the rest of the obtained sequence (Fig. 2). Thus, a target site mutation is not involved in the resistance mechanism, and our results suggest non-target site resistance mechanism(s) are likely engaged on these accessions. In other studies, a mutation at amino acid 2078 (numbered respect to that of *Alopecurus myosuroides* Huds.) consisting of Asp to Glu was reported in a resistant barnyardgrass accession (Fang et al., 2020).

Practical Applications

In this study, we have gathered more information about the resistance mechanism involved in cyhalofop and fenoxaprop-resistant barnyardgrass accessions from Arkansas. This knowledge will be useful when designing weed management programs and at the same time represents a further challenge since other resistance mechanisms such as herbicide-metabolism are most likely the cause of resistance.

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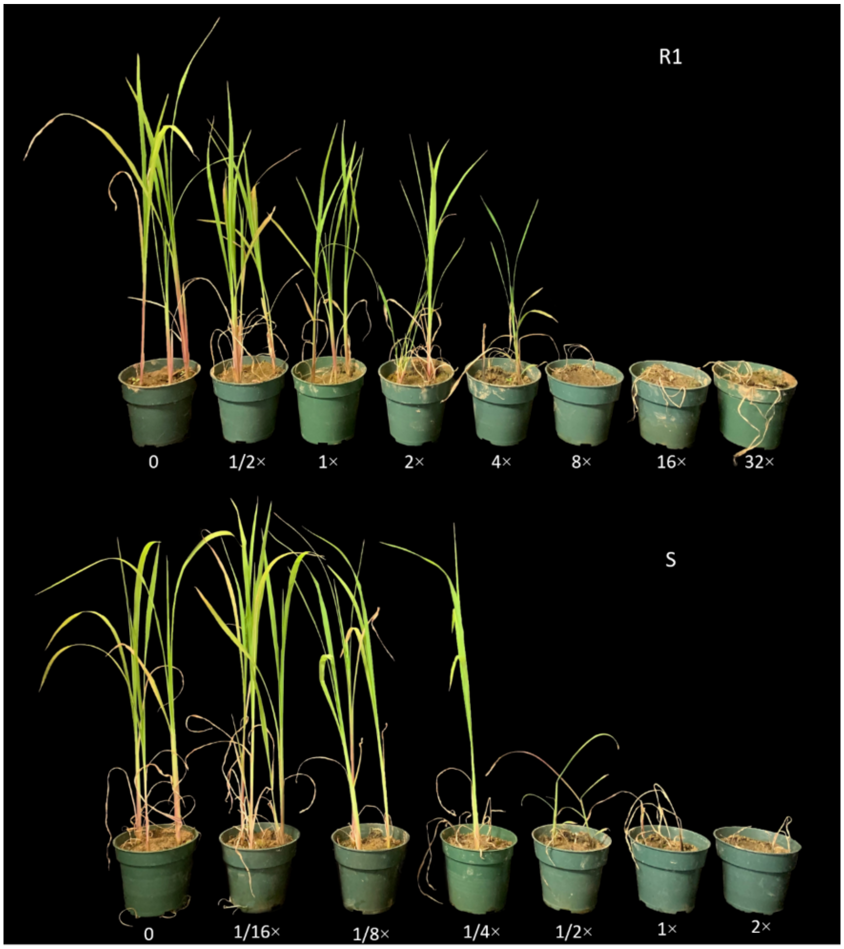

Fig. 1. Representative photo of a dose-response curve of barnyardgrass treated with cyhalofop. × represents the respective herbicide rate applied. R1: resistant accession; S: susceptible accession. Photos were taken 21 days after the cyhalofop treatment.

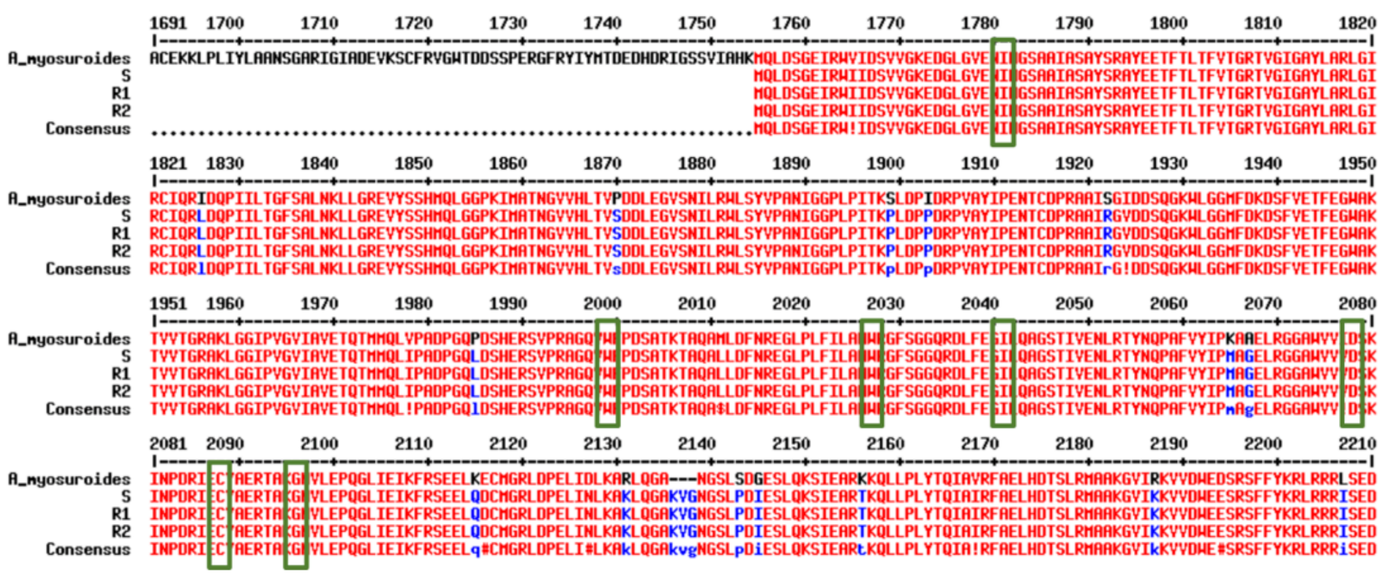

Fig. 2. Partial alignment of barnyardgrass *ACCase gene*. Sequences were aligned to that of *A. myosuroides* (A_ myosuroides) (GenBank accession AJ310767.1). S: susceptible; R1 and R2: resistant accessions. Boxes display amino acid positions described previously in conferring resistance to acetyl CoA carboxylase (ACCase)-inhibiting herbicides.

Evaluating the Tolerance of FullPage™ Rice to Acetolactate Synthase (ALS) Inhibiting Herbicides

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Abstract

Across the mid-South, herbicide-resistant Italian ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot.] has been a problematic competitor to multiple crops, with limited effective control measures. Sulfonylureas have been found effective in controlling glyphosate-resistant ryegrass in fields planted to corn. FullPage™ rice was released in 2020 on a limited basis and has been found to provide increased tolerance to imazethapyr herbicide. Two experiments were conducted on a silt loam soil in Tillar, Arkansas, in 2020 to determine the tolerance of FullPage™ rice to sulfonylurea herbicides applied preemergence (PRE) and postemergence (POST). Treatments consisted of Resolve Q (rimsulfuron + thifensulfuron) at 1.25 and 0.625 oz/ac, Steadfast Q (nicosulfuron + rimsulfuron) at 1.5 and 0.75 oz/ac, and Accent Q (nicosulfuron) at 0.75 and 0.375 oz/ac. When applied PRE, minimal levels of stunting were observed from most treatments within two weeks after application. When applied POST, crop stunting, chlorosis, leaf malformation, and necrosis were observed from most treatments, with crop stunting being more prevalent throughout the season. Within 14 days after the POST application (DAPOST), all treatments exhibited varying levels of stunting and chlorosis, with both rates of Steadfast Q resulting in the highest levels of injury. Similarly, by 35 DAPOST the rates of Steadfast Q continued to exhibit observable levels of stunting. Regardless of the levels of phytotoxicity earlier in the growing season, rice yields were comparable across all treatments when compared to the weed-free check. Overall, applying sulfonylurea herbicides PRE resulted in little to no injury and no yield reduction, which may allow these herbicides to be utilized to control herbicide-resistant Italian ryegrass before rice being planted or at planting. Although no yield reduction was observed when these herbicides were applied POST, significant levels of phytotoxicity were observed from all treatments.

Introduction

Herbicide-resistant Italian ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot.], has been a prevalent early-season competitor to multiple crops, including rice (*Oryza sativa* L.) across the mid-South, with resistance to some acetolactate synthase (ALS) inhibitors, ACCase inhibiting herbicides, and glyphosate (Bond et al., 2014). Fall applied Group 15 herbicides have been used to control Italian ryegrass; however, they have been shown to cause yield reduction in the following year to rice (Lawrence et al., 2018). Rimsulfuron and nicosulfuron containing products have been used to control Italian ryegrass at planting or before planting corn (Butts et al., 2020). In 2020, FullPage™ rice was introduced as improved imidazolinone (IMI)-tolerant hybrid cultivars and may offer some tolerance to sulfonylurea herbicides due to its dual gene IMI resistance.

Procedures

Two experiments were conducted on a silt loam soil in Tillar, Arkansas in 2020, to determine the tolerance of FullPage™ rice to preemergence (PRE) and postemergence (POST) applications of sulfonylurea herbicides. Both experiments were conducted as a randomized complete block design with four replications, and FullPage™ RT 7321 FP was drilled at 30 lb/ac with plot sizes of 6.33 ft by 30 ft. In both experiments, sulfonylurea herbicide treatments were applied either PRE or 4- to 5-leaf rice growth stage and consisted of Resolve Q® (rimsulfuron + thifensulfuron) at 1.25 and 0.625 oz/ac, Steadfast Q® (nicosulfuron + rimsulfuron) at 1.5 and 0.75 oz/ac, and Accent Q® (nicosulfuron) at 0.75 and 0.375 oz/ac. All treatments were applied with 0.25% v/v nonionic surfactant. Treatments were applied with a compressed air-pressurized tractor-mounted sprayer calibrated to deliver 12 GPA using Teejet® AIXR 110015 nozzles traveling 3.5 mph. Visual phytotoxicity ratings were taken at 7, 14, and 35 days after the POST application (DAPOST) and were compared to a weed-free check, in addition to crop yields being taken. These data were subjected to an analysis of variance, and means were separated by Fisher's protected least significant difference with a *P*-value of 0.05.

Results and Discussion

Stunting was observed from most PRE-treatments up to two weeks after application; however, no further injury or yield reduction was observed throughout the season (data not shown). When applied POST, various types of phytotoxicity were observed, including stunting, chlorosis, leaf malformation (data not shown), and necrosis (data not shown). At 7 DAPOST, rice stunting and chlorosis was observed from all treatments, ranging from 3% to

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30% (Table 1). A rate response was observed, with most treatments that were applied at a higher rate resulted in greater injury than the lower rates applied. Overall, Steadfast Q® resulted in >25% stunting and chlorosis at 7 DAPOST, regardless of the rate (Table 1). At 14 DAPOST, stunting from most treatments had dissipated except for Steadfast Q® at 0.75 and 1.5 oz/ac and Resolve Q® at 1.25 oz/ac, with 25%, 26%, and 13% stunting, respectively (Table 2). By 35 DAPOST, both rates of Steadfast Q® continued to exhibit observable levels of stunting over that of other treatments (Table 3). Despite the observed injury earlier in the season, comparable yields were observed from all treatments, as well as the weed-free check ranging from 164 to 172 bu./ac (Table 4).

Practical Applications

When applied at planting, applications of sulfonylurea herbicides caused little injury and no yield loss, which may allow for the possible use of these herbicides to control Italian ryegrass before or at planting with FullPage™ rice. When applied POST, these data suggest that although no yield reduction was observed from any treatment, significant levels of phytotoxicity were observed within two weeks after the POST application. Further research needs to be conducted on varying soil types, especially soils with higher pH.

Acknowledgments

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Table 1. FullPage™ rice stunting and chlorosis at 7 days after the postemergence application.

Treatments	Rate(s)	Application Timing	Stunting	Chlorosis
	oz/ac		------------------------%	------------------------
Weed-free check			0	0
Resolve Q	1.25	4- to 5-leaf rice	26	25
Steadfast Q	1.5	4- to 5-leaf rice	30	25
Accent Q	0.75	4- to 5-leaf rice	10	20
Resolve Q	0.625	4- to 5-leaf rice	18	21
Steadfast Q	0.75	4- to 5-leaf rice	30	27
Accent Q	0.375	4- to 5-leaf rice	3	13
LSD (*P* = 0.05)			8	12

Table 2. FullPage™ rice stunting and chlorosis at 14 days after the postemergence application.

Treatments	Rate(s)	Application Timing	Stunting	Chlorosis
	oz/ac		------------------------%	------------------------
Weed-free check			0	0
Resolve Q	1.25	4- to 5-leaf rice	13	18
Steadfast Q	1.5	4- to 5-leaf rice	26	21
Accent Q	0.75	4- to 5-leaf rice	0	9
Resolve Q	0.625	4- to 5-leaf rice	0	15
Steadfast Q	0.75	4- to 5-leaf rice	25	24
Accent Q	0.375	4- to 5-leaf rice	0	3
LSD (*P* = 0.05)			6	7

Table 3. FullPage™ rice stunting at 35 days after the postemergence application.

Treatments	Rate(s)	Application Timing	Stunting
	oz/ac		%
Weed-free check			0
Resolve Q	1.25	4- to 5-leaf rice	0
Steadfast Q	1.5	4- to 5-leaf rice	10
Accent Q	0.75	4- to 5-leaf rice	0
Resolve Q	0.625	4- to 5-leaf rice	0
Steadfast Q	0.75	4- to 5-leaf rice	10
Accent Q	0.375	4- to 5-leaf rice	0
LSD (P = 0.05)			5

Table 4. FullPage™ rice yields following the postemergence application.

Treatments	Rate(s)	Application Timing	Yield
	oz/ac		bu./ac
Weed-free check			167
Resolve Q	1.25	4- to 5-leaf rice	165
Steadfast Q	1.5	4- to 5-leaf rice	164
Accent Q	0.75	4- to 5-leaf rice	172
Resolve Q	0.625	4- to 5-leaf rice	167
Steadfast Q	0.75	4- to 5-leaf rice	169
Accent Q	0.375	4- to 5-leaf rice	165
LSD (P = 0.05)			12

Postemergence Timing of Residual Herbicides for Grass Control in Arkansas Row Rice

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Abstract

In recent years, furrow-irrigated (row) rice acreage has increased in Arkansas rice production as a result of the increased benefits of water conservation, time, labor, and costs; albeit, some concerns of increased pest management issues exist to control problematic weed species without the benefit of established flood conditions. In the absence of flooded conditions, the utilization of residual herbicides throughout the season is needed. In 2020, two experiments were conducted, one in Tillar, Arkansas, and the other in Marianna, Arkansas, to determine the most effective residual herbicide program to control problematic grass species in furrow-irrigated rice. Herbicide programs contained clomazone applied preemergence (PRE) alone or in tank-mixture with quinclorac followed by (fb) various residual herbicides applied postemergence (POST) at 14 and 21 days after the PRE (DAPRE) application. Regardless of the location, the inclusion of quinclorac in tank-mixture with clomazone applied PRE provided greater control of barnyardgrass and broadleaf signalgrass than when clomazone was applied alone. Regardless of the POST application timing in Tillar, clomazone at 0.3 lb ai/ac plus quinclorac at 0.375 lb ai/ac applied PRE fb pendimethalin at 0.5 lb ai/ac plus thiobencarb at 3 lb ai/ac provided greater than 95% control of barnyardgrass. In Tillar, Arkansas, greater than 90% control of broadleaf signalgrass was observed throughout the season from all herbicide programs. The program containing clomazone plus quinclorac applied PRE fb pendimethalin plus thiobencarb provided the greatest control of barnyardgrass in Marianna. These data suggest that the use of multiple residual herbicides will be beneficial in controlling problematic grass weeds in furrow-irrigated rice.

Introduction

Furrow-irrigated (row) rice acreage has increased over the past few years in Arkansas rice production due to such advantageous benefits as water conservation, time, labor, and costs (Tacker, 2007). However, some concerns exist for the possible change in pests that are normally observed in flooded rice production (Tracy et al., 1993). With the lack of weed control via flooded conditions, increased weed pressure will be a concern in furrow-irrigated rice production (Bagavathiannan et al., 2011), which will likely result in the need to use more residual herbicides throughout the season.

Procedures

Two experiments were conducted in 2020, one in Tillar, Arkansas, and the other in Marianna, Arkansas, to determine the most effective residual herbicide program and timing to provide control of problematic grasses in furrow-irrigated rice (*Oryza sativa* L.). The problematic grasses evaluated in these experiments included barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.) and broadleaf signalgrass [*Urochloa platyphylla* (Munro ex. C. Wright) R.D. Webster]. Both experiments were set up as a randomized complete block design, and RT 7321 FP rice was drill seeded at 30 lb/ac with four replications and plot sizes of 6.33 ft by 30 ft. Visual efficacy ratings were taken at 14 and 36 days after the final POST application (DAPOST) in Tillar, Arkansas, and at 7 and 14 DAPOST in Marianna, Arkansas, in addition to being compared to a nontreated check. Herbicide programs consisted of clomazone (Command®) at 0.3 lb ai/ac applied preemergence (PRE) alone or in tank-mixture with quinclorac (Facet L®) at 0.375 lb ai/ac. PRE applications were followed by (fb) postemergence (POST) residual herbicides, such as the pre-mix of clomazone plus pendimethalin (RiceOne®) at 1.05 lb ai/ac, pendimethalin (Prowl H_20®) at 0.5 lb ai/ac, and thiobencarb (Bolero®) at 3 lb ai/ac. POST applications were applied 14 days after the PRE application (DAPRE) and 21 DAPRE. Herbicide programs were applied with a compressed air-pressurized tractor-mounted sprayer calibrated to deliver 12 gal/ac using Teejet® AIXR 110015 nozzles traveling at 3.5 mph. Weed efficacy data were subjected to an analysis of variance, and means were separated by Fisher's protected least significant difference test with a *P*-value of 0.05.

Results and Discussion

Regardless of the location, clomazone + quinclorac applied PRE provided greater control of barnyardgrass than clomazone applied PRE alone (Tables 1 and 3). In Tillar, clomazone at 0.3 lb ai/ac fb pendimethalin at 0.5 lb ai/ac + thiobencarb at 3 lb ai/ac at 14 DAPRE provided increased control of barnyardgrass compared to applying at 21 DAPRE (Table 1). Programs with clomazone at 0.3 lb ai/ac + quinclorac at 0.375 lb ai/ac applied at planting fb pendimethalin at 0.5 lb ai/ac + thiobencarb 3 lb ai/ac provided greater than 95% control of barnyardgrass regardless of the POST application timing (Table 1). Greater than 90% control of broadleaf signalgrass was observed throughout the

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season in Tillar, Arkansas from all herbicide programs (Table 2). In Marianna, Arkansas, variable barnyardgrass control was observed due to frequent heavy rainfall events (Table 3). Similar to what was observed in Tillar, Arkansas, clomazone at 0.3 lb ai/ac + quinclorac at 0.375 lb ai/ac PRE fb pendimethalin at 0.5 lb ai/ac + thiobencarb at 3 lb ai/ac provided the greatest control of barnyardgrass with 84% control at 14 DAPRE (Table 3).

Practical Applications

Based on these data, the utilization of multiple residual herbicides incorporated into a herbicide program is necessary to provide control of problematic grass weeds, such as barnyardgrass, in furrow-irrigated rice. Tank-mixing clomazone at 0.3 lb ai/ac with quinclorac at 0.375 lb ai/ac applied at planting, providing increased control of barnyardgrass than when clomazone at 0.3 lb ai/ac was applied alone. Regardless of the location or timing of the second application, clomazone 0.3 lb ai/ac + quinclorac at 0.375 lb ai/ac fb pendimethalin at 0.5 lb ai/ac + thiobencarb at 3 lb ai/ac providing increased control of barnyardgrass. However if clomazone is used alone at planting, then the second application of residuals should occur no later than 14 days after the PRE application.

Acknowledgments

Special thanks to the University of Arkansas System Division of Agriculture and the Arkansas Rice Checkoff Program administered by the Arkansas Rice Research and Promotion Board.

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Table 1. Barnyardgrass control 14 and 36 days after the postemergence application in Tillar, Arkansas.

Programs[a]	Rate(s)	Application timing	14 DAPOST[b]	36 DAPOST
	lb ai/ac		----------%----------	
Nontreated check			0	0
Clomazone	0.3	PRE	50	81
Clomazone + quninclorac	0.3 + 0.375	PRE	76	91
Clomazone fb pendimethalin + thiobencarb	0.3 fb 0.5 + 3	PRE fb 14 DAPRE	90	99
Clomazone fb pendimethalin + thiobencarb	0.3 fb 0.5 + 3	PRE fb 21 DAPRE	67	86
Clomazone fb clomazone* + pendimethalin*	0.3 fb 1.05*	PRE fb 14 DAPRE	60	74
Clomazone fb clomazone* + pendimethalin*	0.3 fb 1.05*	PRE fb 21 DAPRE	80	94
Clomazone fb clomazone* + pendimethalin* + thiobencarb	0.3 fb 1.05* + 3	PRE fb 14 DAPRE	86	87
Clomazone fb clomazone* + pendimethalin* + thiobencarb	0.3 fb 1.05* + 3	PRE fb 21 DAPRE	99	97
Clomazone + quinclorac fb pendimethalin + thiobencarb	0.3 + 0.375 fb 0.5 + 3	PRE fb 14 DAPRE	97	94
Clomazone + quinclorac fb pendimethalin + thiobencarb	0.3 + 0.375 fb 0.5 + 3	PRE fb 21 DAPRE	85	95
LSD (P = 0.05)			25	18

[a] Programs 6, 7, 8, and 9 containing clomazone + pendimethalin POST was applied as RiceOne®, and an asterisk (*) denotes the herbicides in this pre-mix as well as the rate.

[b] Abbreviations: DAPRE = days after the PRE application; DAPOST = days after the POST application; fb = followed by; PRE = preemergence; and POST = postemergence.

Table 2. Broadleaf signalgrass control 14 and 36 days after the postemergence application in Tillar, Arkansas.

Programs[a]	Rate(s)	Application timing	14 DAPOST[b]	36 DAPOST
	lb ai/ac		---------------------%--------------------	
Nontreated check			0	0
Clomazone	0.3	PRE	95	97
Clomazone + quninclorac	0.3 + 0.375	PRE	90	98
Clomazone fb pendimethalin + thiobencarb	0.3 fb 0.5 + 3	PRE fb 14 DAPRE	97	99
Clomazone fb pendimethalin + thiobencarb	0.3 fb 0.5 + 3	PRE fb 21 DAPRE	93	99
Clomazone fb clomazone* + pendimethalin*	0.3 fb 1.05*	PRE fb 14 DAPRE	97	99
Clomazone fb clomazone* + pendimethalin*	0.3 fb 1.05*	PRE fb 21 DAPRE	95	98
Clomazone fb clomazone* + pendimethalin* + thiobencarb	0.3 fb 1.05* + 3	PRE fb 14 DAPRE	96	99
Clomazone fb clomazone* + pendimethalin* + thiobencarb	0.3 fb 1.05* + 3	PRE fb 21 DAPRE	99	99
Clomazone + quinclorac fb pendimethalin + thiobencarb	0.3 + 0.375 fb 0.5 + 3	PRE fb 14 DAPRE	99	99
Clomazone + quinclorac fb pendimethalin + thiobencarb	0.3 + 0.375 fb 0.5 + 3	PRE fb 21 DAPRE	97	98
LSD (P = 0.05)			7	3

[a] Programs 6, 7, 8, and 9 containing clomazone + pendimethalin POST was applied as RiceOne®, and an asterisk (*) denotes the herbicides in this pre-mix as well as the rate.

[b] Abbreviations: DAPRE = days after the PRE application; DAPOST = days after the POST application; fb = followed by; PRE = preemergence; and POST = postemergence.

Table 3. Barnyardgrass control 7 and 14 days after the postemergence application in Marianna, Arkansas.

Programs[a]	Rate(s)	Application Timing	7 DAPOST[b]	14 DAPOST
	lb ai/ac		---------------------%--------------------	
Nontreated check			0	0
Clomazone	0.3	PRE	56	45
Clomazone + quninclorac	0.3 + 0.375	PRE	60	61
Clomazone fb pendimethalin + thiobencarb	0.3 fb 0.5 + 3	PRE fb 14 DAPRE	56	20
Clomazone fb pendimethalin + thiobencarb	0.3 fb 0.5 + 3	PRE fb 21 DAPRE	30	30
Clomazone fb clomazone* + pendimethalin*	0.3 fb 1.05*	PRE fb 14 DAPRE	65	45
Clomazone fb clomazone* + pendimethalin*	0.3 fb 1.05*	PRE fb 21 DAPRE	50	45
Clomazone fb clomazone* + pendimethalin* + thiobencarb	0.3 fb 1.05* + 3	PRE fb 14 DAPRE	63	40
Clomazone fb clomazone* + pendimethalin* + thiobencarb	0.3 fb 1.05* + 3	PRE fb 21 DAPRE	56	38
Clomazone + quinclorac fb pendimethalin + thiobencarb	0.3 + 0.375 fb 0.5 + 3	PRE fb 14 DAPRE	87	76
Clomazone + quinclorac fb pendimethalin + thiobencarb	0.3 + 0.375 fb 0.5 + 3	PRE fb 21 DAPRE	77	79
LSD (*P* = 0.05)			21	17

[a] Programs 6, 7, 8, and 9 containing clomazone + pendimethalin POST was applied as RiceOne®, and an asterisk (*) denotes the herbicides in this pre-mix as well as the rate.

[b] Abbreviations: DAPRE = days after the PRE application; DAPOST = days after the POST application; fb = followed by; PRE = preemergence; and POST = postemergence.

Non-target-site resistance of barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] to florpyrauxifen-benzyl

J.I. Hwang,[1] J.K. Norsworthy,[1] T.R. Butts,[2] and L.T. Barber[2]

Abstract

An arylpicolinate herbicide, florpyrauxifen-benzyl (FPB), is used to control barnyardgrass (BYG), which is a troublesome weed in rice agriculture. In FPB resistance screening and dose-response experiments previously conducted, we found one susceptible (Sus) and three FPB-resistant (R1, R2, and R3) BYG biotypes that had no mutations in genes of target site proteins. For these BYG biotypes, absorption, translocation, and metabolism of carbon-14 labeled ([^{14}C]-) FPB were evaluated to reveal the potential resistance mechanisms. Absorption of [^{14}C]-FPB in Sus BYG increased over time and reached 90%, which was >10 percentage points greater than that in R biotypes. The [^{14}C]-FPB absorption in all R BYG equilibrated after 48 h. For both Sus and R BYG, most [^{14}C]-FPB absorbed was present in the treated leaf (79.8−88.8%), followed by untreated aboveground (9.5–18.6%) and belowground tissues (1.3−2.2%). Differences between Sus and R BYG biotypes were also found for FPB metabolism. Production of the active metabolite, florpyrauxifen-acid, was greater in Sus BYG (21.5−52.1%) than in R BYG (5.5−34.9%). In conclusion, reductions in FPB absorption and florpyrauxifen-acid production contribute to the inability to control some BYG biotypes with FPB.

Introduction

A major concern for Arkansas rice producers is controlling troublesome summer annual weeds like barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.; BYG] (Norsworthy et al., 2013). Profitable rice agriculture relies on the use of herbicides to mitigate yield loss and reductions in milling quality (Andres et al., 2013). A rice herbicide, florpyrauxifen-benzyl (FPB), is a synthetic auxin inhibitor (WSSA Group IV) commercialized by Corteva Agrisciences (Indianapolis, Indiana, USA) in 2018, under the trade name Loyant™ with Rinskor™ active (US EPA, 2017). In a BYG screen to FPB conducted the winter following the commercial launch of the herbicide, some BYG accessions were not adequately controlled in the greenhouse when timely applications were made under ideal conditions for optimum activity of the herbicide. Yet, there have been no published studies and records about the occurrence and mechanism of FPB resistance in BYG.

Procedures

Based on previous results of FPB resistance screening and dose-response experiments conducted for 170 BYG seeds collected from mid-southern USA rice fields (data not shown), one susceptible (Sus) and three apparent resistant (R) BYG biotypes were selected to be used for the resistance mechanism study. The R BYG biotypes selected were previously confirmed for no mutations in genes of the target-site proteins such as *transporter inhibitor response1 (TIR1)* and *auxin signaling box (AFB)* (data not shown).

To evaluate the potential of non-target-site resistance evolution in Sus and R BYG plants, absorption, translocation, and metabolism of FPB were examined using its phenyl ring-labeled carbon-14 ([^{14}C]) standard (Corteva Agriscience™, Indianapolis, Indiana, USA). Before [^{14}C]-FPB treatment, 4-leaf seedlings of each BYG biotype were applied with 74 g ai/ac of non-radioactive herbicide (i.e., Loyant™) containing 1% (v/v) methylated seed oil concentrate (MSO). Within 30 min after the non-radioactive herbicide application, all BYG plants were treated with 1.72 kBq of [^{14}C]-FPB and grown in a growth chamber programmed at 14/10 h day/night cycle with 86/77 °F day/night temperatures. Plant samples of each BYG biotype were collected 24, 48, and 72 h after [^{14}C]-herbicide treatment. Absorption of [^{14}C]-FPB was calculated by subtracting the [^{14}C]-activity analyzed from methanol rinsates of the treated leaf at each sampling time from the initially analyzed [^{14}C]-activity. Barnyardgrass samples for translocation evaluations were dissected into treated leaf, non-treated aboveground, and belowground tissues, and then the [^{14}C]-activity in each tissue sample was analyzed using biological oxidizer and liquid scintillation analyzer. Time-dependent translocation of [^{14}C]-FPB to each plant part was calculated as the proportion of the [^{14}C]-activity measured in each tissue sample at each sampling time relative to the [^{14}C]-activity absorbed in each sampling time. Time-dependent metabolism of [^{14}C]-FPB in BYG samples was analyzed for the entire plant tissue without dissection, and the parent compound and two metabolites such as florpyrauxifen-acid (FPA) and florpyrauxifen-hydroxy acid (FPHA) were quantified using a high-performance liquid chromatography−radiation detector (HPLC−RAD).

Results and Discussion

Foliar absorption of [^{14}C]-FPB applied to all tested BYG biotypes was observed in the range of 58−90%. The [^{14}C]-FPB

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absorption for Sus BYG plants increased over time, while the absorption for R BYG plants equilibrated after 48 h (Fig. 1). The reduced herbicide absorption observed in some R biotypes at 72 h may contribute some to the FPB resistance (Jugulam and Shyam, 2019). Most of the [^{14}C]-herbicide absorbed was present in the treated leaf (80−89%), and the limited translocation of FPB to non-treated aboveground (12−19%) and belowground (< 2%) tissues was observed in the 72-h period (Fig. 2). The herbicide translocation observed in the R BYG biotypes did not differ from the Sus standard (P = 0.05); therefore, changes in translocation do not likely influence BYG sensitivity to FPB. Differences between Sus and R BYG biotypes were also found for [^{14}C]-FPB metabolism. Total metabolism of [^{14}C]-FPB observed in this study did not give any ideas to infer the resistance mechanism because the differences between Sus and R BYG biotypes were non or less significant (P = 0.05) (Fig. 3). However, analytical results of an active acid form metabolite [^{14}C]-FPA indicated significant differences between Sus and R biotypes (Fig. 4). Over the entire study period, the production of [^{14}C]-FPA in R biotypes (5.5−35%) was less than that in the Sus biotype (22−52%) (P = 0.05). Since the conversion of FPB to FPA in weeds can be closely related to the herbicide's efficacy, the reduced conversion to or rapid breakdown of [^{14}C]-FPA may be a crucial mechanism to endow FPB resistance to BYG. The production of [^{14}C]-FPHA in the Sus biotype (6.7−21%) was similar to R biotypes (6.5−35%); therefore, changes in the conversion process of FPB or FPA to FPHA are not likely to explain the reduced sensitivity in R biotypes.

Practical Applications

Overall results of the present study demonstrate that the evolution of FPB resistance in BYG is attributed to reductions in FPB absorption and FPA production. Since FPB is a relatively recently developed herbicide, very little is known about its resistance occurrence and mechanism in weeds. Thus, our findings in this study may be crucial to seek ways of mitigating or overcoming evolutions of FPB resistance in BYG and further, to inspire the development of new herbicide actives.

Acknowledgments

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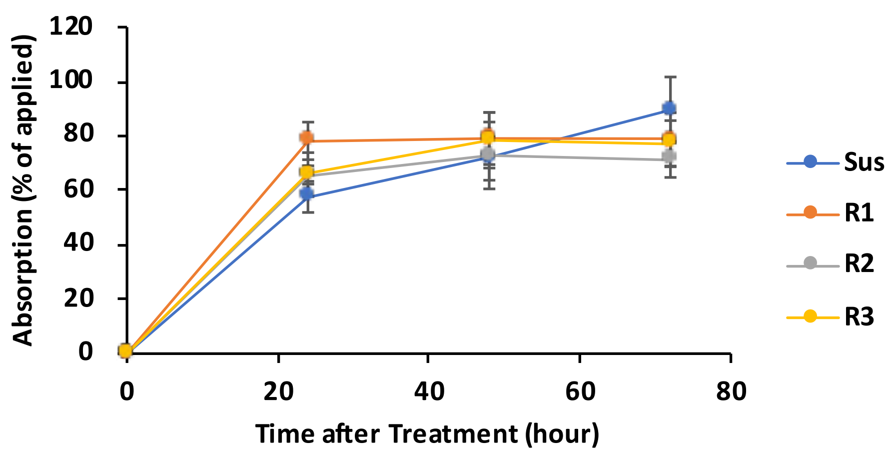

Fig. 1. Foliar absorption of [^{14}C]-florpyrauxifen-benzyl by susceptible (Sus) and three resistant (R1, R2, and R3) barnyardgrass biotypes. Data points represent mean values (n = 6), and error bars represent standard deviations. Based on paired t-test results, significant differences between Sus and R biotypes are indicated with asterisk marks (*) (P < 0.05).

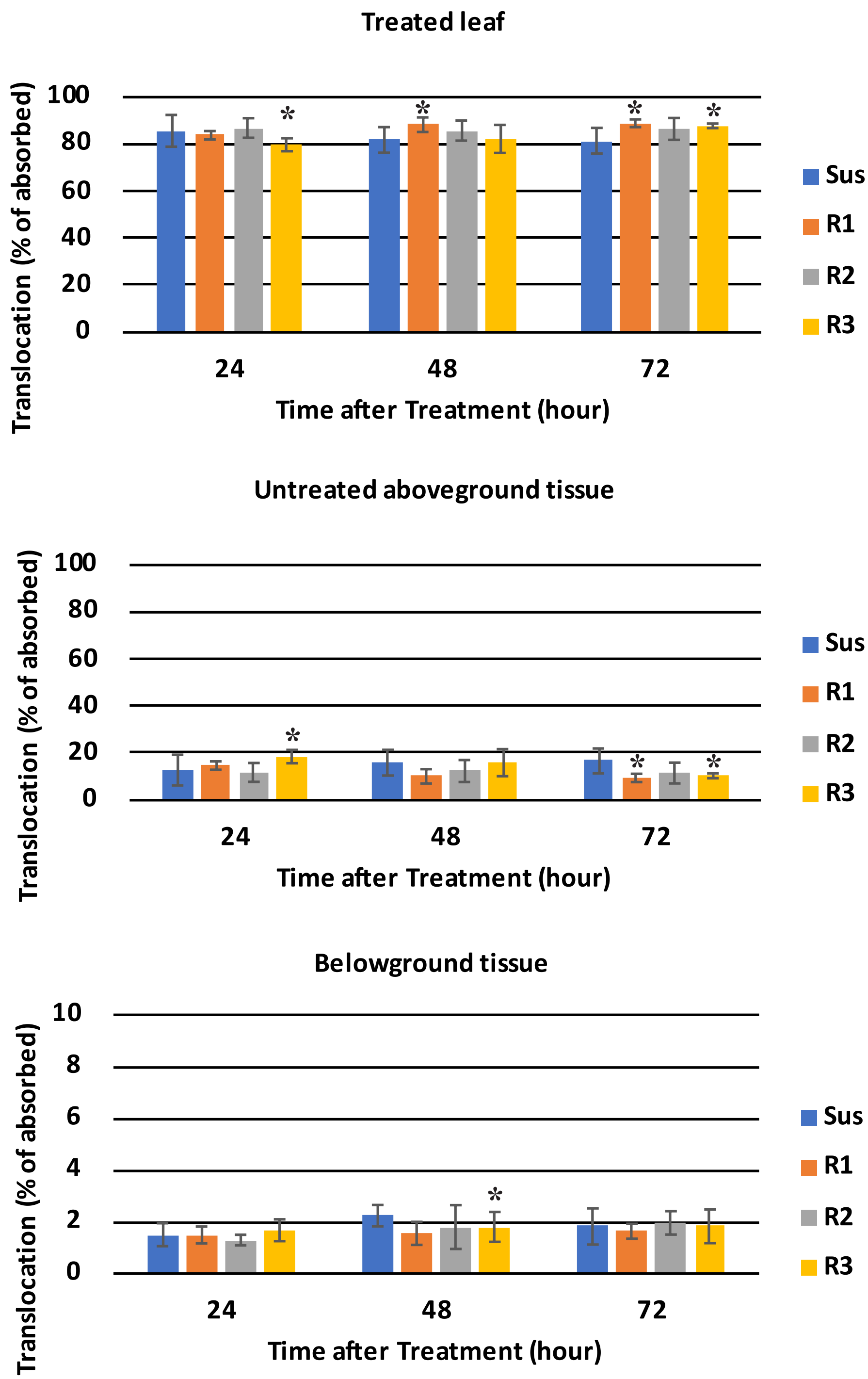

Fig. 2. Translocation of [^{14}C]-florpyrauxifen-benzyl absorbed in susceptible (Sus) and three resistant (R1, R2, and R3) barnyardgrass biotypes. Data bars represent mean values (*n* = 6), and error bars represent standard deviations. Based on paired *t*-test results, significant differences between Sus and R biotypes are indicated with asterisk marks (*) (*P* < 0.05).

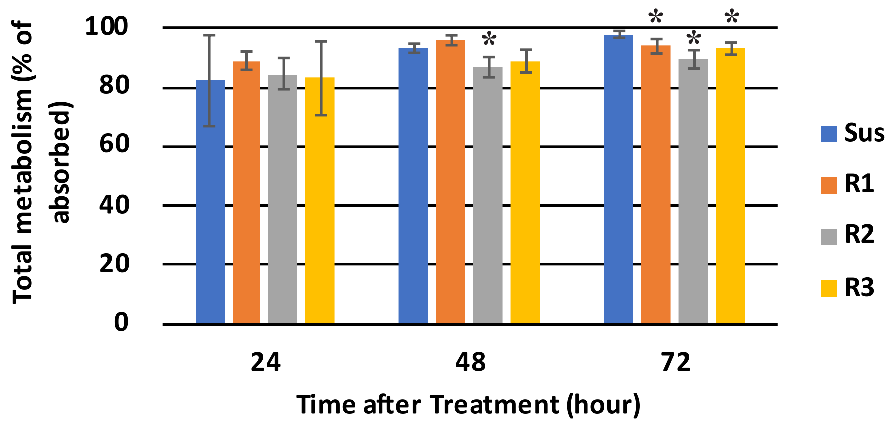

Fig. 3. Total metabolism of [^{14}C]-florpyrauxifen-benzyl (FPB) in susceptible (Sus) and three resistant (R1, R2, and R3) barnyardgrass biotypes. Data points represent mean values (*n* = 6), and error bars represent standard deviations. Based on paired *t*-test results, significant differences between Sus and R biotypes are indicated with asterisk marks (*) (*P* < 0.05).

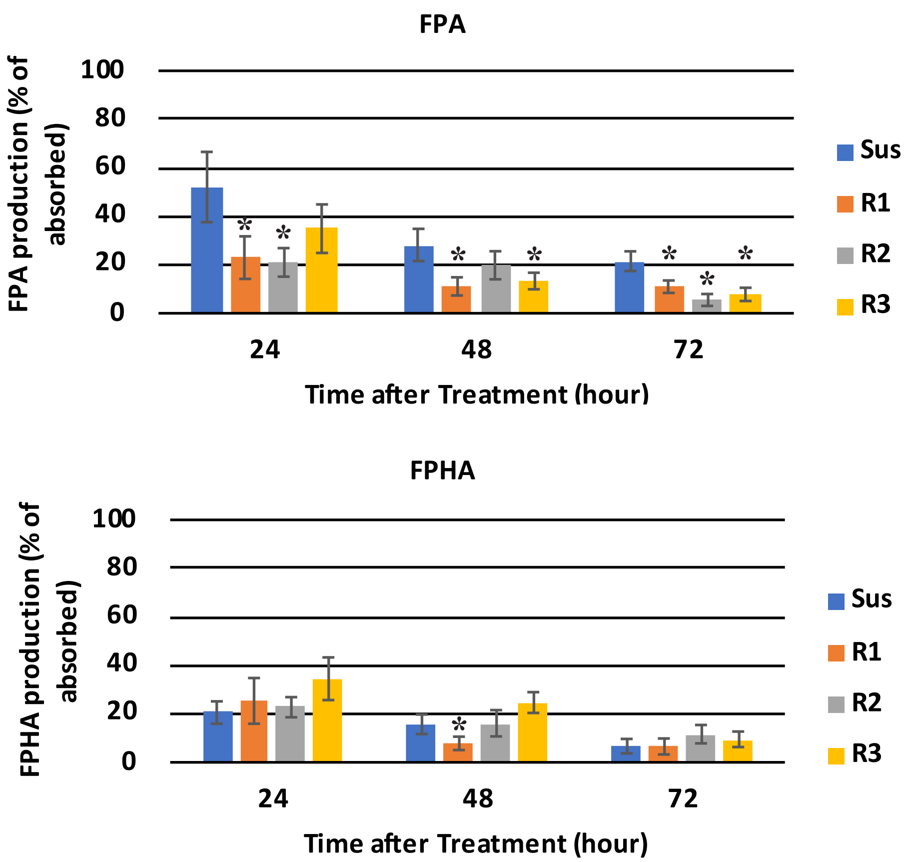

Fig. 4. Metabolism of [^{14}C]-florpyrauxifen-benzyl in susceptible (Sus) and three resistant (R1, R2, and R3) barnyardgrass biotypes. FPA and FPHA are florpyrauxifen-acid and florpyrauxifen-hydroxy acid, respectively. Data bars represent mean values (*n* = 6), and error bars represent standard deviations. Based on paired *t*-test results, significant differences between Sus and R biotypes are indicated with asterisk marks (*) (*P* < 0.05).

The Influence of Tank-Mix Partners on Max-Ace Rice Crop Response and Weed Control

M.L. Zaccaro,[1] J.K. Norsworthy,[1] T. Barber,[2] T.R. Butts,[2] M.M. Houston,[1] and L.B. Piveta[1]

Abstract

RiceTec will soon release Max-Ace™ rice that will allow quizalofop, produced by ADAMA, to be applied to the crop to remove unwanted grasses. A field trial was conducted in 2020 to verify crop safety and weed control options with the new quizalofop proprietary formulation produced by ADAMA. Quizalofop was applied in a sequential application or in combination with commonly used herbicides to develop programs that would improve the length of residual and spectrum of control. Results showed that the injury sustained was acceptable, and no impacts on grain yield were observed. In addition, all herbicide programs effectively controlled barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.) (≥98%) and weedy rice (*Oryza sativa* L.) (≥96%). According to these results, the new quizalofop formulation should be further evaluated as a valuable weed management tool for Max-Ace™ rice production.

Introduction

According to a survey, more options to control barnyardgrass and weedy rice are needed in rice fields in the Midsouth (Norsworthy et al., 2013). A collaboration between RiceTec and ADAMA Agricultural Solutions is anticipated leading to the launch of Max-Ace™ rice varieties and an accompanying proprietary formulation of quizalofop (Boyd, 2021). This technology will be an alternative for rice growers to the FullPage and Clearfield systems. Preliminary research reports that Max-Ace™ is comparable to BASF's Provisia technology; however, due to high levels of injury, Provisia herbicide will not be allowed over-the-top of Max-Ace™ rice (J.K. Norsworthy, pers. comm.). Recently, ADAMA has released the HighCard herbicide, a new proprietary formulation of quizalofop herbicide with a safener that protects the Max-Ace rice from damage; however, the herbicide has not yet been introduced to the market or extensively tested (Boyd, 2021). Quizalofop is not a new herbicide, as it was introduced in the late 1980s for grass control in soybean (Shaner, 2014). The selective activity derives from the mechanism of action, which allows for inhibition of acetyl-CoA carboxylase in grasses, leading to the growth inhibition of shoot and root tissue, followed by necrosis, and eventually plant death (Takano et al., 2021).

Therefore, due to the novelty of the HighCard herbicide, as well as Max-Ace rice, our objective was to evaluate crop safety and weed control utility of herbicide programs that included ADAMA's new quizalofop product with common rice herbicides. We hypothesized that these herbicide programs would provide safety to the Max-Ace rice and improve weed control.

Procedures

A field experiment was conducted in 2020 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas, on a Dewitt silt loam soil. A long-grain, pure-line Max-Ace rice variety (RTV 7231) was drill-seeded on 11 April at a rate of 16 seeds/row-ft, and then plots were established measuring 6 ft by 17 ft. Herbicide treatments were made at two timings, an early postemergence (EPOST) on 5 May and another application made pre-flood (PREFL) on 20 May. The rice growth stage at the first application was 1 to 2 leaves, and was at the 4-leaf stage on the second application. The field trial was set as a single-factor randomized complete block design with 11 treatments (herbicide programs) and 4 replications. Herbicide programs included ADAMA's proprietary quizalofop formulation (0.88 lb ai/gal), and applications were made at a rate equivalent to 0.11 lb ai/ac (or 15 fl oz/ac) for all treatments, except for a nontreated check. The herbicide programs tested included ADAMA's new quizalofop formulation with commonly used herbicides to provide residual activity and improve the spectrum of weed control, such as Vopak, Zurax L, Prowl H_2O, Bolero, Permit, Sharpen, Basagran, and Loyant (Table 1). The herbicide treatments were applied using a CO_2-pressurized backpack sprayer coupled with AIXR 110015 nozzles, calibrated to deliver 15 GPA. The experiment was flooded on 22 May. All plots were maintained according to the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations.

Data collection included visible estimations of crop injury and weed control of barnyardgrass and weedy rice at 7 and 14 days after early postemergence (DA EPOST), and 7, 14, and 21 days after pre-flood (DA PREFL) treatments. Rice grain yield was harvested at crop maturity utilizing a small-plot combine. Data were subjected to analysis of variance (ANOVA) in JMP Pro 15 (SAS Institute, Inc., Cary N.C.), and appropriate means were separated using Tukey's honestly significant difference test with a significance level of 0.05.

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Results and Discussion

There was a significant impact from the herbicide programs on crop injury only at 7 DA EPOST ($P = 0.01$). The herbicide program of quizalofop + Basagran at EPOST (treatment 9) resulted in higher injury (21%) when compared to quizalofop + Loyant EPOST (treatment 10) or quizalofop + Zurax L at EPOST (treatment 4), which resulted in 9 and 11% injury, respectively. The other treatments were not statistically different from each other (Table 1). According to evaluations made at 14 DA EPOST and those made after the PREFL application (7, 14, and 21 DA PREFL), herbicide programs caused similar levels of injury, which was no more than 15% (data not shown). As expected, the rice recovered by 21 DA PREFL, and overall visible injury reduced significantly, ranging from 3% to 7% (Table 1). Average rough rice grain yield was impacted by herbicide programs ($P < 0.01$) in comparison to the nontreated check (51 bu./ac) (Table 1). However, there was no difference between programs, which averaged 168 bu./ac.

All herbicide programs tested significantly impacted weed control evaluated at 7 and 14 DA EPOST or at 7, 14, and 21 DA PREFL applications for weedy rice or barnyardgrass control; however, no differences were observed across herbicide programs. At 7 DA EPOST, barnyardgrass control was already 98% or greater for all herbicide programs (Table 2). Barnyardgrass control was very effective from the beginning due to low plant density and small size plants at both application timings. At the EPOST application, barnyardgrass density was on average 2–3 plants/sq ft at the 1-leaf growth stage. By the PREFL application timing, density was 1 plant/sq ft at the 3-leaf growth stage.

Weedy rice control was lower at 7 DA EPOST application, ranging from 13% to 35%. This could be attributed to the fact that quizalofop activity requires translocation and accumulation at the sites of action (meristematic tissues), and symptoms may take time to develop (Shaner, 2014). In addition, weedy rice density at EPOST application was high (5–6 plants/sq ft at the 2-leaf growth stage). By 21 DA PREFL application, weedy rice control improved substantially and was greater than 96% across herbicide programs (Table 2). Even though sequential applications of quizalofop (treatment 2) were an effective treatment to control weedy rice and barnyardgrass in this trial, a weed management program that provides a greater diversity of weed control methods should be recommended to help protect the technology from evolving herbicide resistance (Takano et al., 2021).

Practical Applications

According to this experiment's results, it is possible to include ADAMA's new quizalofop formulation as a viable option for grass control in the Max-Ace rice system. All herbicide programs performed well on barnyardgrass and weedy rice control, achieving high levels of control by 21 DA PREFL. Herbicide programs resulted in low levels of injury, and no impact was observed to rough rice grain yield. The addition of this herbicide system will offer a good alternative for rice growers to reduce the overreliance on technologies such as the Clearfield and Fullpage, to which there is widespread resistance in weedy rice and barnyardgrass (Heap, 2021).

Acknowledgments

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Table 1. Visible injury of Max-Ace rice at 7 days after early postemergence (DA EPOST) and 21 days after pre-flood (DA PREFL) application, and rough rice grain yield influenced by herbicide programs.

Treatment #	Herbicide program†	Visible injury 7 DA EPOST	Visible injury 21 DA PREFL	Rough rice grain yield
		-----% of nontreated-----		bu./ac
1	Nontreated	-	-	51 b
2	quizalofop (EPOST) fb quizalofop (PREFL)§	16 ab‡	7 a	158 a
3	quizalofop + Vopak (EPOST) fb quizalofop (PREFL)	15 ab	6 a	187 a
4	quizalofop + Zurax (EPOST) fb quizalofop (PREFL)	11 b	3 a	155 a
5	quizalofop + Prowl (EPOST) fb quizalofop (PREFL)	19 ab	5 a	166 a
6	quizalofop + Bolero (EPOST) fb quizalofop (PREFL)	14 ab	5 a	166 a
7	quizalofop + Permit (EPOST) fb quizalofop (PREFL)	14 ab	8 a	162 a
8	quizalofop + Sharpen (EPOST) fb quizalofop (PREFL)	19 ab	5 a	184 a
9	quizalofop + Basagran (EPOST) fb quizalofop (PREFL)	21 a	6 a	171 a
10	quizalofop + Loyant (EPOST) fb quizalofop (PREFL)	9 b	6 a	171 a
11	quizalofop (EPOST) fb quizalofop + Loyant (PREFL)	15 ab	5 a	158 a

† Vopak, clomazone, 10 oz/ac; Zurax L, quinclorac, 32 oz/ac; Prowl H_2O, pendimethalin, 40 oz/ac; Bolero, thiobencarb, 48 oz/ac; Permit, halosulfuron-methyl, 1 oz/ac; Sharpen, saflufenacil, 1 oz/ac; Basagran, bentazon, 32 oz/ac; Loyant, florpyrauxifen-benzyl, 12 oz/ac.

‡ Means followed by the same letter within a column are not statistically different according to Tukey's honestly significant difference test with $\alpha = 0.05$.

§ All treatments received crop oil concentrate at 1% v/v, except for treatments containing Loyant, which were applied using methylated seed oil at 10 oz/ac.

Abbreviations: early postemergence (EPOST); pre-flood (PREFL).

Table 2. Barnyardgrass and weedy rice control at 7 days after early postemergence (DA EPOST) and 21 days after pre-flood (DA PREFL) application influenced by herbicide programs for the Max-Ace rice technology.

		Weedy rice control		Barnyardgrass control	
Treatment #	Herbicide program†	7 DA EPOST	21 DA PREFL	7 DA EPOST	21 DA PREFL
		--------------% of nontreated--------------			
1	Nontreated	-	-	-	-
2	quizalofop (EPOST) fb quizalofop (PREFL)§	26 a‡	96 a	99 a	99 a
3	quizalofop + Vopak (EPOST) fb quizalofop (PREFL)	24 a	96 a	99 a	98 a
4	quizalofop + Zurax (EPOST) fb quizalofop (PREFL)	28 a	96 a	98 a	99 a
5	quizalofop + Prowl (EPOST) fb quizalofop (PREFL)	25 a	96 a	99 a	99 a
6	quizalofop + Bolero (EPOST) fb quizalofop (PREFL)	24 a	98 a	99 a	99 a
7	quizalofop + Permit (EPOST) fb quizalofop (PREFL)	35 a	97 a	98 a	99 a
8	quizalofop + Sharpen (EPOST) fb quizalofop (PREFL)	13 a	96 a	99 a	99 a
9	quizalofop + Basagran (EPOST) fb quizalofop (PREFL)	28 a	97 a	99 a	99 a
10	quizalofop + Loyant (EPOST) fb quizalofop (PREFL)	24 a	97 a	98 a	99 a
11	quizalofop (EPOST) fb quizalofop + Loyant (PREFL)	22 a	98 a	99 a	99 a

† Vopak, clomazone, 10 oz/ac; Zurax L, quinclorac, 32 oz/ac; Prowl H_2O, pendimethalin, 40 oz/ac; Bolero, thiobencarb, 48 oz/ac; Permit, halosulfuron-methyl, 1 oz/ac; Sharpen, saflufenacil, 1 oz/ac; Basagran, bentazon, 32 oz/ac; Loyant, florpyrauxifen-benzyl, 12 oz/ac.

‡ Means followed by the same letter within a column are not statistically different according to Tukey's honestly significant difference test with $\alpha = 0.05$.

§ All treatments received crop oil concentrate at 1% v/v, except for treatments containing Loyant, which were applied using methylated seed oil at 10 oz/ac.

Abbreviations: early postemergence (EPOST); pre-flood (PREFL).

Response of Three Rice Cultivars to Gibberellic Acid Seed Treatment

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Abstract

Elongation of shoots in rice (*Oryza sativa*, L.) after germination is a critical step in the growth of the plant. A range of factors can affect rice between germination and emergence from the soil. Finding a way to shorten the time from germination to emergence increases the likelihood of achieving an adequate, uniform stand. One tool that has been previously researched on past rice cultivars is gibberellic acid applied as a seed treatment. Trials were seeded at three University of Arkansas System Division of Agriculture research stations during 2020 to evaluate three current pure-line rice varieties (Diamond, CLL15, and Titan) when treated with 0, 1, or 2 g ai/cwt of gibberellic acid prior to seeding. No significant differences were observed for grain yield or milling yield at any location. The only significant difference in stand density was observed at the Pine Tree Research Station, where there was a cultivar by treatment interaction. There was a significant treatment effect only for Titan, where the control treatment resulted in a significantly higher stand density compared to the 2 g ai/cwt rate of gibberellic acid.

Introduction

Elongation of shoots in rice (*Oryza sativa*, L.) after germination is a critical step in the growth of the plant. Rapid elongation of the coleoptile and mesocotyl allow for earlier seedling emergence and stand establishment. This could lead to more uniform, increased stand density and potentially result in maximized grain yield in a given situation. Adverse conditions can slow down the elongation process and possibly lead to loss of seedling vigor. A reduction in time from planting to emergence can also shorten the time prior to flooding, thereby reducing the number of preflood herbicide applications. One factor that influences rice shoot elongation and ultimately plant emergence is gibberellins.

Gibberellic acid (GA) has been examined as a seed treatment to test if its role accelerates germination and emergence of rice (Dunand, 1993). Results indicate improved shoot elongation and emergence when GA seed treatments are used. However, significant responses were generally only noted when using utilizing deeper seeding depths. The purpose of this test was to determine the effect of GA rate on three cultivars: Diamond, a standard stature long-grain; CLL15, a semi-dwarf long-grain; and Titan, a short stature medium-grain.

Procedures

Diamond, CLL15, and Titan rice seed were treated with CruiserMaxx Rice and Vibrance for insecticide and fungicide seed treatments. Zinche ST (32.5% zinc oxide) was also applied to ensure no zinc deficiencies occurred. The seed of each cultivar was treated with 0, 1, or 2 g ai/cwt of GA. The cultivars were drill-seeded at a rate of 36 seed/ft^2. Plot dimensions were 8 rows (7.5-in. spacing) and 16.5 ft in length. Trials were planted at three University of Arkansas System Division of Agriculture locations including the Rice Research Extension Center (RREC) near Stuttgart, Ark., the Pine Tree Research Station (PTRS) near Colt, Ark., and the Northeast Research and Extension Center (NEREC) near Keiser, Ark. The RREC and the PTRS locations are both silt loam soils while the NEREC location is a silty clay soil. Each trial location was set up as a randomized complete block design with four replications.

Planting dates were 10 April for RREC, 21 April for PTRS, and 21 May for NEREC. Emergence dates were 27 April at RREC, 4 May at PTRS, and 29 May at NEREC. Single preflood nitrogen (N) rates were utilized at each location prior to flood at approximately the 5-leaf stage, with 130 lb N/ac at RREC and PTRS and 160 lb N/ac at NEREC. Trials were flooded within two days after preflood N application. At maturity, the middle four rows of each plot were harvested. Harvest occurred at RREC on 24 August, at PTRS on 9 September, and at NEREC on 29 September. Grain yields were adjusted to a moisture content of 12% and grain weight was reported on a bushels per acre (bu./ac) basis. One bushel of rice is 45 lb. Data were subjected to analysis of variance, PROC GLIMMIX, SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) using a 10% level of significance.

Results and Discussion

There were no significant differences in grain yield among treatments for any location in 2020 (Table 1). In addition, there were no significant differences for milling yield, whether for head rice or total rice (Table 2).

At the RREC and NEREC locations, no significant differences in stand density were observed (Table 3). However at the PTRS, there was a cultivar by treatment interaction. There was a

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significant treatment effect for the cultivar Titan only, where the control treatment resulted in a significantly higher stand density compared to the 2 oz/cwt rate of Release. While no significant differences were observed for Diamond or CLL15 at this location, it should be noted that treatments resulting in the highest numerical stand densities were variable among the three cultivars shown.

While previous studies have shown the benefits of gibberellic acid seed treatments on rice, those benefits were not evident in these trials. Changes in cultivars and planting equipment and/or practices could be responsible for the differences in these results compared to past studies. Planting depth in these studies was approximately 1-in. or less, which is similar to results reported by Dunand (1993). It should also be noted that all seed received insecticide and fungicide seed treatments which have also been shown to improve rice seedling vigor and stand establishment.

Practical Applications

The gibberellic acid seed treatment studies in 2020 agree with previous research that rice seeded at shallow depths generally does not show a response to gibberellic acid seed treatment. Seeding rice at greater depths, or under more adverse conditions, could result in a response to gibberellic acid seed treatment. However, it is not generally recommended as a standard practice. The findings from this study are based on results from silt loam and clay soils with rice seeded at a shallow depth (0.75 to 1.0 in.) into a stale seedbed. Field and environmental conditions should be taken into consideration when determining whether the use of a gibberellic acid seed treatment is warranted.

Acknowledgments

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Table 1. Grain yield response of three rice cultivars to gibberellic acid seed treatments at three locations.

Seed Treatment	Grain Yield		
	RREC†	PTRS	NEREC
	(bu./ac)		
0 g a.i./cwt	185.6	185.9	199.9
1 g a.i./cwt	182.2	195.5	199.3
2 g a.i./cwt	181.5	188.1	197.1
P-Value‡	NS§	NS	NS

† RREC = Rice Research and Extension Center; PTRS = Pine Tree Research Station; and NEREC = Northeast Research and Extension Center.

‡ *P*-Value of 0.05.

§ NS = not significant.

Table 2. Milling yield as affected by gibberellic acid seed treatment rate across three cultivars at three locations.

	Milling Yields		
Seed Treatment	RREC[†]	PTRS	NEREC
	%HR/%TR[‡]		
0 g a.i./cwt	71.4/63.6	71.3/62.3	70.6/62.8
1 g a.i./cwt	71.1/63.2	71.2/63.0	70.8/63.4
2 g a.i./cwt	71.1/63.4	71.5/62.6	70.863.0
P-Value[§]	NS[¶]	NS	NS

[†] RREC = Rice Research and Extension Center; PTRS = Pine Tree Research Station; and NEREC = Northeast Research and Extension Center.

[‡] %HR/%TR = % head rice/% total rice.

[§] *P*-Value of 0.05.

[¶] NS = not significant.

Table 3. Stand density as affected by gibberellic acid seed treatment rate and cultivar at three locations.

	Stand Density				
	RREC[†]	NEREC	PTRS[‡]		
Seed Treatment			Diamond	CLL15	Titan
	(AVG plants/sq. ft)				
0 g a.i./cwt	32.7	23.5	22.7 a[§]	21.3 a	28.2 a
1 g a.i./cwt	32.4	22.7	27.3 a	21.8 a	26.8 ab
2 g a.i./cwt	32.8	22.7	25.8 a	27.1 a	23.7 b
P-Value[¶]	NS[#]	NS	0.1836	0.2647	0.0417

[†] RREC = Rice Research and Extension Center; PTRS = Pine Tree Research Station; and NEREC = Northeast Research and Extension Center.

[‡] PTRS treatment by cultivar was significant.

[§] Means followed by the same letter are not significantly different at P = 0.05.

[¶] *P*-Value of 0.05.

[#] NS = not significant.

Grain Yield Response of Twelve New Rice Cultivars to Nitrogen Fertilization

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Abstract

The purpose of the cultivar × nitrogen (N) studies is to determine the optimal N fertilizer rates for new rice (*Oryza sativa* L.) cultivars across an array of soils and environments in which rice is grown in Arkansas. Twelve cultivars were studied in 2020 and included: ARoma 17, CLL15, CLL16, CLL17, CLM04, DG263L, Diamond, Jewel, Lynx, ProGold1, ProGold2, and PVL02. Seed treatment and seeding rates were determined following current recommendations and production practices. The grain yields were fair to excellent for all the cultivars studied at the three locations in 2020, with lodging ranging from mild to severe for the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) location. The 2020 season was the first year the cultivars CLL17, DG263L, and ProGold2 were included; therefore, there is insufficient data to make a recommendation at this time, but the response to N reported here can serve as a guide while additional data is collected. Multiple years of results for Diamond provide evidence that this cultivar should have good yields with minimal to no lodging if 150 pounds (lb) of N/ac is applied in a two-way split of 105 lb N/ac at the preflood timing followed by 45 lb N/ac at midseason when grown on silt loam soils and 180 lb N/ac in a two way split of 135 lb N/ac at the preflood timing followed by 45 lb N/ac applied at midseason when grown on clay soils.

Introduction

The objectives of the cultivar × nitrogen (N) fertilizer rate trials are to record and analyze the grain yield performance of new rice cultivars over a range of fertilizer rates on a representative clay and two silt loam soils as well as diverse growing environments existing in Arkansas. The goal is to determine the appropriate N fertilizer rates conducive to maximize grain yields and provide sound research-based baseline N management data for Arkansas rice producers. Selections of promising new cultivars from breeding programs in Arkansas, Louisiana, Mississippi, and Texas, as well as from private industry, are evaluated in these trials. The results validate current recommendations for the soil types favorable for rice culture and provide a solid base for N management recommendations for new cultivars as they become available to rice producers.

Procedures

The cultivar x N fertilizer rate studies were conducted at the following locations: University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) near Keiser, Ark., on a Sharkey Clay (Vertic Haplaquepts) soil; the Pine Tree Research Station (PTRS) near Colt, Ark., on a Calloway silt loam (Glossaquic Fragiudalfs) soil; and the Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a Dewitt silt loam (Typic Albaqualfs). The method employed for data analysis for all locations and each cultivar is a randomized complete block design with four replications. Twelve cultivars were included and studied in 2020 at the three locations. The cultivars studied were ARoma 17, CLL15, CLL16, CLL17, CLM04, DG263L, Diamond, Jewel, Lynx, ProGold1, ProGold2, and PVL02. All seed of each cultivar was treated with fungicides and an insecticide according to current recommendations and practices in addition to an application of a zinc seed treatment. All experimental plots were direct-seeded in eight rows at 7.5-in. spacing and 17 ft in length at a rate of 36 seed/ft^2. A single preflood N fertilizer application was employed in all cultivars across all locations as urea treated with a urease inhibitor (NBPT) onto a dry soil surface at the 4- to 5-leaf growth stage. The preflood N rates were: 0, 60, 90, 120, 150, 180, and 210 lb N/ac. The locations with silt loam soils (PTRS and RREC) received the 0 to 180 lb N/ac rate structure, and the study on the clay soil (NEREC) was treated with the 0 to 210 lb of N/ac rate structure with the omission of the 60 lb of N/ac rate. Pertinent agronomic dates and practices for each location are reported in Table 1. The permanent flood was established within 48 hours of the preflood N application and maintained until maturity of the rice crop. At maturity, the flood was released, then within two weeks, the four center rows of each plot were harvested, and the grain moisture content, yield, and lodging were recorded. Yields were calculated as bushels (bu.) per acre (ac) and adjusted to 12% moisture, with a bushel of rice base weight of 45 pounds (lb). Statistical analysis was conducted using PROC GLM, SAS v. 9.4 (SAS Institute, Inc. Cary, N.C.) with means separation using Fisher's least significant difference test (P = 0.05).

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Results and Discussion

In 2008 a single preflood N application was adopted in all cultivar × N studies in response to the rising cost of N fertilizer and the preference of medium to short stature, semi-dwarf, and stiff straw rice plant types that are currently grown. These cultivars typically reach maximal yield potential when less N is applied in a single preflood application in comparison with the traditional two-way split application. Usually, cultivars receiving a single preflood application required 20 to 30 lb N/ac less than when N is applied in a two-way split application where the second application is made between beginning internode elongation and the 0.5-inch internode elongation growth stages. Hence, if 150 lb N/ac is recommended for a two-way application, then 120 to 130 lb N/ac should maximize yield potential using a single preflood application as long as certain critical conditions are met. These conditions include: 1) that the field can be flooded timely, 2) the urea has been treated with the urease inhibitor NBPT or ammonium sulfate is used instead as a source of N, unless the field can be flooded in two days or less for silt loam soils and seven days or less for clay soils, and 3) a flood of 2 to 4 inches is maintained for at least three weeks after flood establishment (Norman et al., 2003; Roberts et al., 2018).

Overall, the yields for the 2020 cultivar × N rate trials were good to excellent for most of the twelve cultivars included. Maximal yields ranged from 163 to 239 bu./ac for the NEREC location, 160 to 241 bu./ac at the PTRS location and 185-242 bu./ac for the RREC location. There was lodging reported for 9 of the 12 entries at the RREC site, with the severity of lodging increasing with the highest preflood N rates. At the other two locations, lodging was reported for only 1 of the 12 entries, PVL02, with the greatest scores recorded as the N rate increased. The lodging at the RREC location was a result of high winds and rain brought by Hurricane Laura, which hit Arkansas County the evening of the 27 August just prior to harvest. Unfortunately, this was followed by rains brought by Tropical Storm Beta and aggravated with the high N rates that suggest the weakening of the straw by the promotion of favorable conditions for disease (Wamishe et al., 2018). Additionally, the increased lodging with higher N rates could be due to the heaviness of the panicles not supported by the stalk under environmental stress on a high-yielding cultivar. In addition, the environmental conditions caused a delay in the planting date for the PTRS and NEREC locations (Table 1), and a greater variability in grain yield response was observed in most cultivars across locations and within N rates. In 2019, planting dates in April yielded an average of about 10 bu./ac more compared to rice planted in early May and up to 20–25 bu./ac above rice planted in late May (Clayton et al,. 2020). Yield results and response to N of Diamond (check cultivar) in this year's cultivar × N trial support data from previous years and indicate that the overall results of the trial align with previous research.

The cultivar ARoma 17 achieved a maximal yield of 189 bu./ac at the RREC location followed by 183 bu./ac at the NEREC and 178 bu./ac at the PTRS when the highest N rates were applied of 180 lb N/ac and 210 N lb/ac for the clay and silt loam locations, respectively (Table 2). The data suggests that this cultivar's yields tend to plateau between 150–180 lb N/ac for clay soils and 120–150 lb N/ac for silt loam soils. The lowest preflood N rate that produced a statistically similar yield to the maximal yield for a given location was identified as 180 lb N/ac for the clay soil and 120 lb N/ac in a single preflood application for the two silt loam soils, similar to results obtained the previous year (Castaneda-Gonzalez et al., 2020). Minimal lodging (30% approximate) was recorded at the 150 and 180 lb N/ac treatments for the RREC location only. The response of this cultivar to N fertilization appears to be linear. These results, in combination with last year's data, suggests that this variety will yield in the range of 180 bu./ac with minimal to no lodging when a single application of 120 lb N/ac for silt loam soils and 180 lb N/ac for clay soils is provided. Additional data is required to identify the optimal N rate for this cultivar.

The rice cultivar CLL15 showed slightly lower yields than Diamond across the silt loam soils with a drastic reduction of yield for the clay soil location by comparison. A peak yield of 232 bu./ac was recorded at the RREC when 120 lb N/ac was applied and 206 bu./ac at the PTRS with the same treatment (Table 3). The yields at the NEREC were 20–40 bu./ac lower than those reported for PTRS and RREC with a peak yield of 163 bu./ac when 180 lb N/ac was applied. The lowest yield-maximizing N rate was 120, 150, and 180 lb N/ac for the RREC, PTRS and NEREC locations, respectively. Lodging was reported for CLL15 only for the RREC location, with a minimum of 12% for the 90 lb N/ac treatment and a maximum of 67% at the 180 lb N/ac rate but no lodging for the 120 lb N/ac treatment. Yield response for this cultivar is quadratic, meaning that once the maximal yield is achieved with a particular N treatment, any additional N has no statistically significant effect or the response is actually negative, i.e., yield decreases. This cultivar displays a stable trend of grain yield production with minimal to no lodging reported except for the highest N rate and under environmental stress, and the results are consistent with those of last year. The lowest yield maximizing N rates were 90, 150, and 150 lb N/ac for the RREC, PTRS, and NEREC locations, respectively. Additional research is needed to refine the preflood N rates for this cultivar, but it appears that when well managed, it has a very high yield potential and good standability.

For the cultivar CLL16, peak yields of 177, 225, and 241 bu./ac were realized at the highest or second to highest preflood N rates (Table 4). The response to N fertilization was quadratic for all locations except the PTRS, with the lowest maximizing N rates of 150, 90, and 90 lb N/ac for the NEREC, PTRS, and RREC locations, respectively. For the NEREC and the RREC locations, additional fertilizer beyond the lowest yield maximizing rate results in yields not statistically different or in reduction of yields at the highest N rates. Lodging was reported for the RREC location exclusively with values of 15 and 60% for the highest rates of fertilizer (150 and 180 lb N/ac). Yields are consistent with results from last year, indicating that CLL16 should be able to sustain yields of 180 to 200 bu./ac across different environments and soils with minimal to no lodging.

Peak yields for CLL17 for all locations are comparable to those of Diamond within this year's test. If not for the lodging scores of up to 100% at the RREC location, this cultivar presents an excellent stable yield potential across locations with maximal yields of 195, 208, and 219 bu./ac for NEREC, PTRS, and RREC, respectively (Table 5). The different weather events influencing the 2020 cultivar × N trials complicate the interpretation of results and make it difficult to determine the appropriate N response for CLL17 without additional data. The lowest yield-maximizing N rates for this cultivar were 150, 90, and 60 lb N/ac for the NEREC, PTRS, and RREC locations, respectively. Yield gains above these N levels were not statistically different, or at the highest level at the NEREC location resulted in yield reduction.

Grain yield response for the cultivar CLM04 to N fertilization was quadratic for the PTRS and the RREC locations, reaching peak yield at 229 bu./ac (150 lb N/ac) and 215 bu./ac (120 lb N/ac), respectively, and linear for the NEREC location with a maximal yield of 181 bu./ac when 210 lb N/ac was applied, making it one of the highest and stable yielding cultivars (Table 6). The lowest yield maximizing N rates were 150, 120, and 90 lb N/ac for the NEREC, PTRS, and RREC locations, respectively. Yields were stable for this cultivar across the top two (NEREC) or top three (PTRS and RREC) preflood N rates. This is the second year that CLM04 has been included in the cultivar × N trials and further data is needed to better categorize the preflood N rates for this cultivar. However, due to the stable yield at and above preflood N rates of 120 lb N/ac at the PTRS and RREC locations it appears that this cultivar will most likely perform best with 120 lb N/ac applied in a single preflood N application when planted in silt loam soils and 150 lb N /ac in a single application for clay soils as indicated by the results obtained at the NEREC location for two consecutive years. The results for the RREC location for 2020 should be interpreted with caution for all cultivars due to the compound effect caused by lodging due to environmental phenomena mention above and mild temperatures observed in the spring.

The overall yields of the cultivar DG263L, included for the first time in the cultivar × N studies, were the highest of all cultivars tested in the 2020 cultivar × N trials, being the only cultivar with yields above 200 bu./ac at all locations (Table 7). The peak yields recorded for this cultivar were 239, 243, and 240 bu./ac for the NEREC, PTRS, and RREC, respectively. Lodging scores from 20 to 73% were recorded at the RREC location for the three highest N rates. The yields were excellent and very stable across all soil types and N rates with excellent standability. The lowest yield-maximizing N rates were 150, 90, and 60 lb N/ac for the NEREC, PTRS, and RREC locations, respectively. The overall response to N rates was linear, although any gains in yield above the aforementioned N rates were statistically not different.

The cultivar Jewel recorded a peak grain yield of 230 bu./ac at the 150 lb N/ac rate at the RREC location, 203 bu./ac at the 180 lb N/ac rate at the PTRS location, and 187 bu./ac at the 210 lb N/ac rate at the NEREC location with no lodging for any of the locations (Table 8). Although yields were generally maximized with the highest or second-highest preflood N rates at all locations, there was no statistical yield difference among the two highest preflood N rates at all three sites. The lowest yield maximizing N rate was 150 lb N/ac for the three locations. There was no lodging reported for Jewel at any of the three experimental sites. This differs from last year when Jewel reported the highest grain yields among all cultivars tested, and with the lowest yield maximizing N rates of 150, 120, and 120 lb N/ac for NEREC, PTRS, and RREC locations, respectively. Taking into consideration that the combining cause and effect of the aforementioned environmental phenomenon occurred at harvest time and its influence on planting date, this is a good yielding variety with excellent standability when compared to our check, and requires the collection of more data to make an educated assessment of the best N rates for the different environmental and soil conditions.

Lynx was the only rice cultivar included in the 2019 cultivar × N trial that produced maximal yields at or above 200 bu./ac at all three locations (Castaneda-Gonzalez et al., 2020). In 2020, the maximal yield of Lynx was achieved with the highest preflood N rates at NEREC and PTRS, but the yield was maximized at the RREC location with the rate of 120 lb N/ac (Table 9). Peak yields of 183 (NEREC), 219 (PTRS), and 212 bu./ac (RREC) were realized. A linear yield response was observed at the NEREC location as yield increases occurred with increasing preflood N rate. However, at the PTRS and the RREC locations, yield plateaued with varying preflood N rates. The lowest yield-maximizing N rate was 150, 90, and 90 lb N/ac for the NEREC, PTRS, and RREC locations, respectively. Nitrogen rates above these levels resulted in higher yields numerically but not statistically different, or in lower yields at the higher rates as for the RREC location. There was lodging reported for Lynx only at the RREC location in a range of 50% to 95% score from the low N rate of 90 lb N/ac to the highest N rate. Overall, Lynx offers good to excellent yields with good standability across environmental and soil conditions. Due to the variability in response to preflood N rates across environments and soil types, it is pertinent that further work is conducted on this cultivar to better categorize the correct preflood and total N rate.

The 2020 growing season represents the second year that the rice cultivar ProGold1 was included in the cultivar × N trials (previously listed as ARX7-1084). In this year's trials, ProGold1 was one of the three cultivars reaching yields of 200 or more bu./ac in all three locations with yields similar to those of Diamond for the same year (Table 10). However, no lodging was reported for ProGold1 at any sites compared to lodging for Diamond at the highest N rates at the RREC. Peak yields of 201, 213 and 242 bu./ac were recorded for the NEREC, PTRS, and RREC, respectively, at either of the two highest N rates. While yield seems to increase with N rate, at least for the PTRS and RREC locations, rates above 120 lb N/ac for silt loam soils and 180 lb N/ac for clay soils result in yield increases not statistically different or in reduction of yield as is the case for the NEREC location. ProGold1 offers an excellent stable yield potential with good standability in diverse environmental and soil conditions according to the results obtained in the two years of study, and with subsequent data will be possible to make general recommendations of N fertilizer requirements for this cultivar.

The yield response of the cultivar ProGold2, in its first season of inclusion in the cultivar × N studies, was stable across N rates and locations. Recorded peak yields were 180, 204, and 228 bu./ac when the two highest N rates were applied for the NEREC, PTRS, and RREC locations, respectively (Table 11). Although, the lowest yield maximizing N rates were found to be 150 lb N/ac for NEREC, 120 lb N/ac for PTRS, and 150 lb N/ac for RREC.

There was no lodging recorded for any of the three locations, hence ProGold2 displays excellent standability. Any yield gains due to increased N rates above the aforementioned lowest yield maximizing rates were found to be not statistically different.

This was the second year the cultivar PVL02 was included in the cultivar × N trials. Yields for this cultivar ranged from moderate to good at the three locations, with the overall highest yields reported at the PTRS location. Peak yields for PVL02 were 166, 180 and 159 bu./ac at the NEREC, PTRS, and RREC locations, respectively (Table 12). The preflood N rate required to produce maximal yield at each location varied greatly and ranged from 180 lb N/ac at NEREC to 90 lb N/ac at RREC. Cultivar PVL02 was the only one with lodging reported at all locations during the 2020 growing season. Lodging scores ranged from 7% to 23% at the highest N rates at the NEREC location, scores of 5% for the intermediate N rate and 30–35% lodging scores for the highest N rates at PTRS, and lodging scores ranging from 56% to 98% from the low to the highest N rate at the RREC location. The lowest yield-maximizing N rate was 150, 90, and 90 lb N/ac for the NEREC, PTRS, and RREC locations, respectively.

Practical Applications

The cultivar × N fertilizer rate trials are a key component of assessing new rice cultivars and developing baseline preflood N and season total N fertilizer requirements to maximize grain yield and productivity. The primary objective is to record and analyze the grain yield performance of new rice cultivars over a range of fertilizer rates on representative soils as well as diverse growing environments in the Arkansas rice-growing region. Therefore, the result of these trials can be utilized to provide the proper N fertilizer rates to achieve maximal grain yields when grown commercially in the Arkansas rice-growing region. Within the cultivar × N trials, we intend to restrict effects other than fertilizer rate; the effect of variables not subject to manipulation like the weather underlines the need for multi-year testing. The 2020 growing season was a year of opportunity to test the sustainability of yields under unusual environmental conditions. The rice cultivars included in 2020 were: ARoma 17, CLL15, CLL16, CLL17, CLM04, DG263L, Diamond, Jewel, Lynx, ProGold1, ProGold2, and PVL02. Most cultivars included in the 2020 cultivar × N trial are in the second year of assessment, and results were confounded with the effects of weather phenomena, therefore more data collection for all cultivars tested needs to be obtained in order to make any suggestions of N recommendation in the future.

Acknowledgments

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Table 1. Pertinent agronomic information for the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2020.

Practices	NEREC	PTRS	RREC
Pre-plant Fertilizer	---------------	17 April 2020 0-60-90-10	6 April 2020 0-60-90
Planting Dates	21 May 2020	6 May 2020	10 April 2020
Herbicide Spray Dates and Spray Procedures	21 May 1 qt Roundup + 1.3 pt Command + 43 oz Facet L + 0.75 oz Permit Plus	6 May 3.2 oz League + 24 oz Facet L + 8 oz Command	21 April 4 oz League + 10 oz Command
Flush Dates	none	none	none
Emergence Dates	29 May 2020	18 May 2020	27 April 2020
Herbicide Spray Dates and Spray Procedures	12 June 24 oz Ricestar + 32 oz Prowl H_2O + 1% COC	26 May 4 qt Propanil + 33 oz Prowl	19 May 32 oz Facet L + 32 oz Prowl
Herbicide Spray Dates and Spray Procedures	10 July 15 oz Clincher	11 June 4 qt RiceBeaux	28 May 1.5 oz Gambit
Preflood N Dates	16 June 2020	17 June 2020	1 June 2020
Flood Dates	17 June 2020	18 June 2020	2 June 2020
Insecticide Spray Dates and Spray Procedures	none applied	none applied	none applied
Drain Dates	7 September 2020	8 September 2020	28 August 2020
Harvest Dates	29 September 2020	17 September 2020	10 September 2020

[a] COC = crop oil concentrate.

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of Aroma 17 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2020.

	Grain Yield[a]		
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	--	**(bu./ac)**	--
0	80.3	85.8	117.3
60	----	141.4	160.1
90	134.7	157.4	181.2
120	153.5	166.6	185.5
150	169.0	176.0	189.2 [35]
180	178.4	178.2	155.6 [32.5]
210	183.3	----	----
$LSD_{(\alpha = 0.05)}$[b]	10.3	10.0	24.1
C.V.[c]	4.6	4.4	9.7

[a] The numbers in superscript to the side of the grain yield are lodging percentages.
[b] LSD = least significant difference.
[c] C.V. = coefficient of variation.

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of CLL15 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2020.

	Grain Yield[a]		
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	--	**(bu./ac)**	--
0	72.3	87.0	140.4
60	----	148.2	191.8
90	134.9	173.7	226.9 [12.5]
120	149.6	189.6	232.1
150	160.6	206.2	217.0 [25]
180	163.1	206.4	183.4 [67]
210	156.5	----	----
$LSD_{(\alpha = 0.05)}$[b]	23.9	18.3	17.5
C.V.[c]	11.4	7.2	5.5

[a] The numbers in superscript to the side of the grain yield are lodging percentages.
[b] LSD = least significant difference.
[c] C.V. = coefficient of variation.

Table 4. Influence of nitrogen (N) fertilizer rate on the grain yield of CLL16 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2020.

	Grain Yield[a]		
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	**(bu./ac)**		
0	79.6	114.7	137.1
60	----	175.5	190.9
90	148.0	202.7	240.9
120	160.3	211.4	238.3
150	171.8	212.0	233.6 [15]
180	177.3	225.4	192.7 [65]
210	171.2	----	----
$LSD_{(\alpha = 0.05)}$[b]	17.2	14.4	29.9
C.V.[c]	7.6	5.0	9.7

[a] The numbers in superscript to the side of the grain yield are lodging percentages.
[b] LSD = least significant difference.
[c] C.V. = coefficient of variation.

Table 5. Influence of nitrogen (N) fertilizer rate on the grain yield of CLL17 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2020.

	Grain Yield[a]		
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	**(bu./ac)**		
0	85.6	97.1	152.1
60	----	176.9	216.1 [17.5]
90	162.3	205.3	218.7 [37.5]
120	180.4	205.4	199.3 [85]
150	192.7	207.7	172.8 [100]
180	195.2	204.2	184.2 [75]
210	193.9	----	----
$LSD_{(\alpha = 0.05)}$[b]	9.5	11.8	35.8
C.V.[c]	3.7	4.3	12.5

[a] The numbers in superscript to the side of the grain yield are lodging percentages.
[b] LSD = least significant difference.
[c] C.V. = coefficient of variation.

Table 6. Influence of nitrogen (N) fertilizer rate on the grain yield of CLM04 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2020.

	Grain Yield[a]		
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	----------------	**(bu./ac)**	----------------
0	66.1	119.5	126.9
60	----	184.5	182.0
90	132.0	207.3	210.6 [17.5]
120	157.7	227.9	215.0 [60]
150	168.5	229.4	199.7 [70]
180	172.4	218.9	184.7 [95]
210	181.4	----	----
$LSD_{(\alpha = 0.05)}$[b]	16.9	18.1	28.4
C.V.[c]	7.7	6.1	10.1

[a] The numbers in superscript to the side of the grain yield are lodging percentages.
[b] LSD = least significant difference.
[c] C.V. = coefficient of variation.

Table 7. Influence of nitrogen (N) fertilizer rate on the grain yield of DG263L rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2020.

	Grain Yield[a]		
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	----------------	**(bu./ac)**	----------------
0	101.4	115.8	181.6
60	----	202.5	240.1
90	195.7	232.8	237.3
120	222.9	242.6	234.3 [20]
150	233.8	236.2	239.3 [52.5]
180	238.0	241.7	205.3 [72.5]
210	238.7	----	----
$LSD_{(\alpha = 0.05)}$[b]	12.1	24.2	38.1
C.V.[c]	3.9	7.6	10.9

[a] The numbers in superscript to the side of the grain yield are lodging percentages.
[b] LSD = least significant difference.
[c] C.V. = coefficient of variation.

Table 8. Influence of nitrogen (N) fertilizer rate on the grain yield of Jewel rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2020.

	Grain Yield		
N Fertilizer Rate	NEREC	PTRS	RREC
(lb N/ac)	--(bu./ac)	--	
0	78.5	99.9	131.8
60	----	150.7	190.9
90	145.6	177.3	207.1
120	165.5	180.7	213.8
150	181.1	195.1	230.4
180	185.2	202.9	227.5
210	186.8	----	----
$LSD_{(\alpha = 0.05)}$[a]	12.4	19.6	12.8
C.V.[b]	5.2	7.8	4.3

[a] LSD = least significant difference.

[b] C.V. = coefficient of variation.

Table 9. Influence of nitrogen (N) fertilizer rate on the grain yield of Lynx rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2020.

	Grain Yield[a]		
N Fertilizer Rate	NEREC	PTRS	RREC
(lb N/ac)	--(bu./ac)	--	
0	74.0	117.4	127.3
60	----	180.6	183.6
90	149.8	215.9	200.0 ^{50}
120	164.1	221.0	211.5 $^{62.5}$
150	178.4	219.1	196.7 ^{90}
180	179.4	218.1	180.9 ^{95}
210	182.8	----	----
$LSD_{(\alpha = 0.05)}$[b]	16.2	18.2	21.9
C.V.[c]	6.9	6.2	7.9

[a] The numbers in superscript to the side of the grain yield are lodging percentages.

[b] LSD = least significant difference.

[c] C.V. = coefficient of variation.

Table 10. Influence of nitrogen (N) fertilizer rate on the grain yield of ProGold1 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2020.

	Grain Yield		
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	----------	**(bu./ac)**	----------
0	102.0	95.7	150.0
60	----	168.1	211.5
90	177.4	173.7	218.2
120	182.2	205.1	232.1
150	183.3	211.7	235.3
180	201.0	212.6	241.8
210	198.7	----	----
$LSD_{(\alpha = 0.05)}$[a]	26.8	16.7	12.1
C.V.[b]	10.2	6.2	3.7

[a] LSD = least significant difference.
[b] C.V. = coefficient of variation.

Table 11. Influence of nitrogen (N) fertilizer rate on the grain yield of ProGold2 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2020.

	Grain Yield		
N Fertilizer Rate	**NEREC**	**PTRS**	**RREC**
(lb N/ac)	----------	**(bu./ac)**	----------
0	79.7	99.2	131.2
60	----	164.5	186.5
90	140.4	178.7	204.3
120	162.4	192.7	204.5
150	176.8	203.0	228.3
180	178.4	204.3	228.2
210	179.6	----	----
$LSD_{(\alpha = 0.05)}$[a]	14.0	13.6	18.1
C.V.[b]	6.1	5.2	6.1

[a] LSD = least significant difference.
[b] C.V. = coefficient of variation.

Table 12. Influence of nitrogen (N) fertilizer rate on the grain yield of PVL02 rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2020.

	Grain Yield[a]		
N Fertilizer Rate	NEREC	PTRS	RREC
(lb N/ac)	---------------------------------------(bu./ac)---------------------------------------		
0	80.5	102.5	125.2
60	----	167.7	148.8 [57.5]
90	140.8	180.0 [5]	152.4 [87.5]
120	152.1	179.4 [5]	158.6 [97.5]
150	162.2	160.4 [30]	147.6 [97.5]
180	166.0 [7.5]	148.4 [35]	134.0 [95]
210	141.9 [22.5]	----	----
$LSD_{(\alpha = 0.05)}$[b]	24.6	19.3	24.5
C.V.[c]	11.6	8.2	10.9

[a] The numbers in superscript to the side of the grain yield are lodging percentages.
[b] LSD = least significant difference.
[c] C.V. = coefficient of variation.

Table 13. Influence of nitrogen (N) fertilizer rate on the grain yield of Diamond rice at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2020.

	Grain Yield[a]		
N Fertilizer Rate	NEREC	PTRS	RREC
(lb N/ac)	---------------------------------------(bu./ac) ---------------------------------------		
0	87.5	104.7	146.5
60	----	162.9	218.2
90	165.1	187.5	223.8
120	183.8	196.5	239.7
150	192.7	202.8	242.3 [12.5]
180	217.6	215.7	242.3 [15]
210	212.6	----	----
$LSD_{(\alpha = 0.05)}$[b]	34.9	23.8	15.5
C.V.[c]	13.1	8.9	4.7

[a] The numbers in superscript to the side of the grain yield are lodging percentages.
[b] LSD = least significant difference.
[c] C.V. = coefficient of variation.

Nitrogen Management Strategies for Furrow-Irrigated Rice Production

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Abstract

Furrow-irrigated rice (FIR) (*Oryza sativa* L.) acreage has been steadily increasing over the past several growing seasons. One issue that is likely to be common in FIR is the possible loss of nitrogen (N) via nitrification-denitrification sequences in the alternating aerobic-anaerobic soil conditions. Small-plot trials were established in 2020 at two sites with clay soil texture and three sites with silt loam soil texture, with four of the five sites located within a commercial FIR production field. A split-plot design was utilized with the whole-plot factor being the location within the field (top and bottom) and the split-plot factor being the N management program, of which there were ten with different timing and rate structures. On a clay soil, the superior N management option was a 75-0-75-46 lb N/ac split, which resulted in an average rice grain yield of 204.4 bu./ac and a milling yield of 52.2/70.9 averaged across the top and bottom locations, as neither metric differed between top and bottom of the field. Meanwhile, more options can maximize yield on a silt loam soil, including a 46-46-46-0 lb N/ac split or a three- to four-way split of the recommended singe preflood rate under conventional flood production. Unlike on clay soils, grain yield suffered greatly at the top of the field on a silt loam soil, averaging 26.9 bu./ac less than at the bottom of the field. Results from these studies reflect those from 2018 and 2019 and help to reaffirm the recommendations found in the Arkansas FIR Handbook for maximizing grain and milling yield.

Introduction

In Arkansas prior to 2017, 40,000 or fewer acres utilized the furrow-irrigated rice (FIR) system; however, over 100,000 acres were harvested in 2018 and 2019 (Hardke, 2020). It is estimated that the FIR production system was utilized on 200,000 acres in Arkansas in 2020 (Hardke, pers. comm.). Limited work has been done on nitrogen (N) management of FIR due to the recent influx in acreage, and previous work was completed prior to the introduction of hybrid rice technology to the United States. Hybrid rice cultivars have greater disease resistance packages and larger root systems than pure-line varieties, making them advantageous for FIR production. Hybrid rice cultivars also have an increased ability to take up native soil N compared to pure-line varieties (Norman et al., 2013). Nitrogen management recommendations have been revised recently in Arkansas and now recommend a 3-way split on both clay and silt loam soils (Hardke and Chlapecka, 2020). Silt loam soil N recommendations include three applications of 46 lb N/ac spaced 7–10 days apart, while the clay soil recommendation is to apply 75 lb N/ac at pre-irrigation followed by 75 lb N/ac 10–14 days later followed by 46 lb N/ac 7–10 days after the second application. The following trials were conducted within 5 FIR fields in 2020 to reaffirm the N recommendations set forth in the new Arkansas Furrow-Irrigated Rice Handbook (Hardke and Chlapecka, 2020).

Procedures

Furrow-irrigated rice N management trials were established at 4 commercial farms and 1 University of Arkansas System Division of Agriculture research station in 2020. The commercial sites included 2 on a clay soil texture: Hightower East on a Sharkey-Crevasse complex (very-fine, smectitic, thermic Chromic Epiaquerts and mixed, thermic typic Udipsamments) and Hightower West on a Sharkey silty clay (very-fine, smectitic, thermic Chromic Epiaquerts) (Soil Survey Staff, 2020). Three silt loam sites were also included: Newport on an Amagon and Forestdale silt loam (Fine-silty, mixed, active, thermic Typic Endoaqualfs and Fine, smectitic, thermic Typic Endoaqualfs), Stuttgart on a Stuttgart silt loam (Fine, smectitic, thermic Albaquultic Hapludalfs), and the Rice Research and Extension Center (RREC) on a Dewitt silt loam (Fine, smectitic, thermic Typic Albaqualfs).

Both clay sites utilized 38-in. furrow spacing, while the 3 silt loam sites utilized a 30-in. furrow spacing. The small plot design was a split-plot, with the whole-plot factor being the location within the field (top, where upland conditions existed, and bottom, where flooded conditions generally existed) and split-plot factor being N management program, of which there were 10. The top and bottom of the field were set up separately as randomized complete block (RCB) designs with 4 replications. Each plot was 3 beds in width and 17 ft in length. Approximately a 4- to 8-in.

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flood was held at the bottom of both clay sites and the Newport site, a 1- to 4-in. flood was held at the bottom of the RREC site, and less than a 1-in. flood was held at the bottom of the Stuttgart site. The hybrid cultivar RT XP753 was grown at Burdette East and Newport, RT 7521 FP was grown at Burdette West and Stuttgart, and RT 7301 was grown at RREC. The previous crop at all sites was soybean [*Glycine max* (L.) Merr.].

The general preflood (PF) N recommendation for RT XP753 and RT 7521 FP behind soybean, 150 lb N/ac, was utilized at both clay sites. The N-STaR program recommended PF rate was utilized to determine the base season total N rate for each of the silt loam sites—75 lb N/ac at Newport, 120 lb N/ac at Stuttgart, and 125 lb N/ac at RREC. Nitrogen applications were applied in weekly intervals where week 1 was applied pre-irrigation (V5–V6) and week 4 corresponded to approximately the green ring stage (Tables 1 and 2). Nitrogen applications are denoted by all 4 weekly application rates as (Week 1- Week 2- Week 3- Week 4) a percentage of single preflood (SPF) recommended rate or in lb N/ac. Applications began on 21 May at Burdette West and Burdette East, 2 June at Newport, 18 June at Stuttgart, and 29 June at RREC. Total N uptake samples were taken at 50% heading from a 3 ft section of a bordered non-harvest row—23 July at Burdette West and Burdette East, 28 July at Newport, 3 August at Stuttgart, and 20 August at RREC. The 50% heading stage is relatively easy to identify, and maximum fertilizer N recovery has occurred at this growth stage (Norman et al., 1992). Harvest occurred on 8 September at Hightower East and Hightower West, 16 September at Newport, 30 September at Stuttgart, and 6 October at RREC.

Field management other than N fertilization was generally consistent with University of Arkansas System Division of Agriculture recommendations. The interval between irrigations averaged approximately once every 4–7 days at all sites. Measures included normalized difference vegetative index (NDVI) using Greenseeker (Trimble Inc., Sunnyvale, Calif.) at half-inch internode (R1), heading date, total N uptake, canopy height, rice grain yield, and milling yield. All measures were analyzed with PROC GLIMMIX using SAS v. 9.4 (SAS Institute, Inc. Cary, N.C.) and a 5% level of significance.

Results and Discussion

Across the two clay sites, there was a significant treatment effect for rice grain yield ($P < 0.0001$), head rice yield ($P < 0.0001$), and total rice yield ($P = 0.0437$). There was also a significant location of the field main effect for head rice yield ($P < 0.0001$). Rice grain yield was maximized with either a 75-0-75-46 lb N/ac split or a single pre-irrigation application of 210 lb N/ac (Table 3). This mirrors the conclusions from the previous two years of research on clay soils (Hardke and Chlapecka, 2020). Head rice yield was maximized only by the single pre-irrigation application of 210 lb N/ac. Head rice yield, averaged across all treatments, was also 8.1% greater at the bottom end of the field compared to the top end of the field (Table 4). Total rice yield was maximized by all treatments other than the four-way split application (38-37-38-37 lb N/ac split).

Averaged across the three silt loam sites, there was a significant treatment main effect for grain yield ($P < 0.0001$), head rice yield ($P < 0.0001$), and total rice yield ($P < 0.0001$). There was also a significant location of the field main effect for grain yield ($P = 0.0141$) and head rice yield ($P < 0.0001$). Grain yield was maximized by multiple treatments, including several three-way splits, four-way splits, and a 150% of recommended single pre-irrigation application (Table 5). Grain yield also averaged 26.9 bu./ac greater at the bottom of the field than the top of the field. Head rice yield and total rice yield were maximized by the 46 lb-46 lb-46 lb-46 lb N/ac split, but total rice yield was also maximized by the 50%-50%-46 lb/ac split. Head rice yield, like grain yield, was also greater at the bottom of the field and averaged 8.4% greater.

Practical Applications

Grain yield results from 2020 fall in line with recommendations in the Arkansas Furrow-Irrigated Rice Handbook, which is based upon 2018 and 2019 results from similar trials. A 75-0-75-46 lb N/ac rate structure remains superior on a clay soil, while more options are available to maximize yield on a silt loam soil and a higher N rate is not necessarily required. A program of three weekly applications of 46 lb N/ac is able to maximize yield on a silt loam soil, as well as a three- or four-way split of the recommended SPF rate for flooded rice production.

One interesting note from 2020 is the difference between the top of the field, where upland conditions exist, and the bottom of the field, where a flood is generally held. There was no difference in yield between the top and bottom of the field on a clay soil, but there was a 26.9 bu./ac advantage at the bottom of the field on a silt loam soil. Additionally, the top of the field produced a significantly lower percentage of head rice compared to the bottom on both soil textures. Head rice yield averaged 8.1–8.4% less at the top of the field. These results suggest that one should be prepared for a significant reduction in both grain yield and milling yield, particularly for head rice, when growing FIR. However, the plots located at the top end of the field were only 100–200 feet away from the irrigation pipe, and yield reduction is likely less as the distance from the irrigation pipe increases. Therefore, this steep yield reduction should not be expected across the entirety of the field, but certainly the upper one-third to one-half and possibly more in a situation where water cannot be backed up into the bottom of the field. The results from these trials help to solidify previous N management recommendations in FIR and hopefully allow producers to maintain both grain and milling yield when transitioning acres into FIR production.

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Table 1. Furrow-irrigated rice nitrogen (N) management treatments at both clay sites in Mississippi County, Arkansas in 2020.

Treatment	Total N Rate	Week 1†	Week 2	Week 3	Week 4
	--------------------------(lb N/ac)---------------------------				
Control	0	-	-	-	-
150-0-0-0	150	150	-	-	-
75-0-75-0	150	75	-	75	-
75-38-37-0	150	75	38	37	-
38-37-75-0	150	38	37	75	-
38-37-38-37	150	38	37	38	37
75-0-75-46	196	75	-	75	46
46-46-46-0	138	46	46	46	-
210-0-0-0	210	210	-	-	-
46-46-46-46	184	46	46	46	46

† Pre-irrigation.

Table 2. Furrow-irrigated rice nitrogen (N) management treatments at the three silt loam sites in eastern Arkansas in 2020.

Treatment	Total N Rate	Week 1†	Week 2	Week 3	Week 4
(% SPF‡ recommendation)	-------------------------(% of SPF or lb N/ac)----------------------				
Control	0	-	-	-	-
100%	100%	100%	-	-	-
50%-50%	100%	50%	-	50%	-
50%-25%-25%	100%	50%	25%	25%	-
25%-25%-50%	100%	25%	25%	50%	-
25%-25%-25%-25%	100%	25%	25%	25%	25%
50%-50%-46 lb	100% + 46 lb	50%	-	50%	46
46 lb-46 lb-46 lb	138 lb	46	46	46	-
150%	150%	150%	-	-	-
46 lb-46 lb-46 lb-46 lb	184 lb	46	46	46	46

† Pre-irrigation.

‡ Single preflood.

Table 3. Mean rice grain yield, head rice (whole kernel) yield, and total rice yield by nitrogen (N) treatment, averaged across top and bottom locations, of furrow-irrigated rice N management trials in 2020 on clay soils in Mississippi County, Arkansas.

Treatment	Rice Grain Yield	Head Rice	Total Rice
(lb N/ac)	(bu./ac)	-------------(%)-------------	
Control	111.4 e[†]	48.8 d	70.9 ab
150-0-0-0	185.2 bcd	51.8 bc	71.2 a
75-0-75-0	196.1 bc	49.7 d	70.9 a
75-38-37-0	189.2 bcd	50.1 cd	70.9 a
38-37-75-0	175.8 cd	50.8 bcd	71.1 a
38-37-38-37	189.0 bcd	49.0 d	70.5 b
75-0-75-46	204.4 ab	52.2 b	70.9 a
46-46-46-0	171.7 d	49.9 d	71.0 a
210-0-0-0	221.4 a	54.6 a	71.0 a
46-46-46-46	194.2 bc	50.6 bcd	70.9 a

[†] Means followed by the same letter within a column are not significantly different using a protected least significant difference test at α = 0.05.

Table 4. Mean head rice (whole kernel) yield by location in the field, averaged across nitrogen (N) treatments, of furrow-irrigated rice N management trials in 2020 on clay soils in Mississippi County, Arkansas.

Location	Head Rice
	(%)
Top	46.7 b[†]
Bottom	54.8 a

[†] Means followed by the same letter within a column are not significantly different using a protected least significant difference test at α = 0.05.

Table 5. Mean rice grain yield, head rice yield (whole kernel), and total rice yield by nitrogen (N) treatment, averaged across top and bottom locations, of furrow-irrigated rice N management trials in 2020 on silt loam soils in Arkansas.

Treatment	Grain Yield	Head Rice	Total Rice
(% SPF† recommendation or lb N/acre)	**(bu./ac)**	-----------%-----------	
Control	139.2 d‡	48.3 d	70.0 e
100%	193.5 bc	53.3 c	70.9 cd
50%-50%	186.7 c	54.4 c	70.9 cd
50%-25%-25%	191.3 bc	54.4 c	71.0 c
25%-25%-50%	195.6 abc	54.0 c	70.6 d
25%-25%-25%-25%	196.9 abc	54.5 c	70.9 cd
50%-50%-46 lb	205.0 ab	57.2 b	71.4 ab
46 lb-46 lb-46 lb	203.1 ab	56.3 b	71.2 bc
150%	201.2 abc	56.3 b	71.2 bc
46 lb-46 lb-46 lb-46 lb	210.6 a	58.7 a	71.6 a

† Single preflood.

‡ Means followed by the same letter within a column are not significantly different using a protected least significant difference test at α = 0.05.

Table 6. Mean rice grain yield and head rice yield (whole kernel) by location within the field, averaged across nitrogen (N) treatments, of furrow-irrigated rice N management trials in 2020 on silt loam soils in Arkansas.

Location	Grain Yield	Head Rice
	(bu./ac)	**(%)**
Top	178.2 b†	50.5 b
Bottom	205.1 a	58.9 a

† Means followed by the same letter within a column are not significantly different using a protected least significant difference test at α = 0.05.

Response of Diamond Rice to Starter Fertilizer Applications on a Silt Loam at Different Growth Stages

J.L. Chlapecka,[1] M.J. Lytle,[1] D.L. Frizzell,[2] and J.T. Hardke[2]

Abstract

A starter nitrogen (N) application is currently not recommended in Arkansas rice production; however, results from recent studies have suggested that a starter N application could result in increased yield on a clayey soil. Little work in this arena has been done on a silt loam soil; thus a study was initiated in 2020 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) to determine the impacts of a starter fertilizer application on rice grain yield, milling, and plant height. Three starter fertilizer treatments were examined: no starter fertilizer, ammonium sulfate (AMS) at 100 lb/ac, and diammonium phosphate (DAP) at 100 lb/ac. The 1-leaf, 2-leaf, and 3- to 4-leaf application timings were examined, which were all planted and emerged at different dates. Results showed a significant increase in grain yield with AMS application at the 2-leaf and 3- to 4-leaf stage, while head rice yield increased with the AMS application at the 2-leaf stage only. However, no grain or milling yield differences were observed at the 1-leaf application timing or with DAP applied at any stage. Starter fertilizer applications also had little effect on rice height. These results suggest that applying AMS as a starter fertilizer to direct-seeded, delayed-flood rice grown on a silt loam soil may provide some benefit under specific conditions but should not be considered as a standard practice at this time. It is, however, worth exploring the use of AMS as a starter fertilizer, as numerical yield benefits were noted across all 3 planting dates and application timings.

Introduction

In flooded rice culture, most nitrogen (N) uptake comes from N fertilization from emergence to reproductive growth (Norman et al., 2003). Therefore, it is possible that rice under the direct-seeded, delayed-flood production system could benefit from the use of starter fertilizer applications prior to establishing a permanent flood. Recent research on clay soils near Rohwer, Ark. and Stoneville, Miss. showed that starter N in the form of ammonium sulfate (AMS), diammonium phosphate (DAP), or N-(n-butyl) thiophosphoric triamide (NBPT)-treated urea was able to significantly increase canopy coverage (Martin et al., 2020). The study also showed that starter N had the potential to increase rice grain yield of RT Gemini 214 CL, CL153, and RT CLXL745. Therefore, a study was initiated in 2020 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas to study the effect of starter fertilizer applications at different growth stages on Diamond rice.

Procedures

Starter fertilizer trials were established in 2020 at the RREC on a Dewitt silt loam (Fine, smectitic, thermic Typic Albaqualfs) (Soil Survey Staff, 2020). The pure-line cultivar Diamond was seeded at 36 seed/ft^2 in plots 8 rows (7.5-in. spacing) wide and 16.5-ft in length on 3 planting dates. The planting dates were 27 March, 6 April, and 21 April; and emergence dates were recorded as 9 April, 24 April, and 4 May, respectively. All seed was treated with CruiserMaxx Rice + Vibrance at 7.12 oz/cwt and Zinche ST at 8.0 oz/cwt. Rice was grown using the University of Arkansas System Division of Agriculture guidelines for rice production. The study was set up and analyzed as a randomized complete block with four replications of each starter fertilizer source within each planting date individually. Starter fertilizer applications were all hand-applied on 13 May; these applications corresponded to 3- to 4-leaf growth stage on the 27 March planting, 2-leaf growth stage on the 6 April planting, and 1-leaf growth stage on the 21 April planting. Three starter fertilizer treatments were utilized: no product applied, 100 lb/ac AMS (21-0-0-24), and 100 lb/ac DAP (18-46-0). Preflood N was applied at the 4- to 5-leaf growth stage at 130 lb N/ac; and the permanent flood was applied within 2 days of preflood N application, where it was then maintained at 2- to 4-in. depth throughout the growing season. Plant heights were taken on 10 plants from each plot at 1, 2, and 3 weeks after starter fertilizer application. The center 4 rows of each plot were harvested at maturity, the moisture content and weight of the grain were determined, and a subsample of harvested grain was removed for milling. Grain yields were adjusted to 12% moisture and reported on a bushels per acre (bu./ac) basis. The dried rice was then milled to obtain percent head rice (%HR; whole kernels) and percent total white rice (%TR) presented as %HR/%TR. All measures, including plant height, grain yield, %HR, and %TR were analyzed with PROC GLIMMIX using SAS v. 9.4 (SAS Institute, Inc. Cary, N.C.) and a 10% level of significance.

Results and Discussion

Rice grain yield was numerically improved by the addition of a starter fertilizer application at all three growth stages prior

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to flooding, regardless of starter fertilizer source. The addition of AMS resulted in a 20.1 bu./ac yield increase (*P* = 0.0183) when applied at the 2-leaf growth stage and a 14.3 bu./ac yield increase (*P* = 0.0851) when applied at the 3- to 4-leaf growth stage compared to where no starter fertilizer was applied (Tables 2 and 3). The first incorporating rainfall (>0.5-in.) did not occur until 18 May, 5 days after all starter fertilizer applications. Starter fertilizer applications prior to the 2- to 3-leaf growth stage are not generally recommended for direct-seeded, delayed-flood rice production in Arkansas; however, the five days between application and incorporation combined with high temperatures above 80 °F allowed the rice to grow at least one additional leaf before the incorporation of the starter fertilizer. Therefore, AMS starter fertilizer applications that resulted in significant yield increase were incorporated near the 3- to 4-leaf stage and the 5-leaf stage. Thus, the current study results align well with what is currently recommended in Arkansas rice production. Rice at the 3- to 5-leaf stage has developed a large enough root system to capture and utilize adequate amounts of AMS applied as a starter fertilizer source. It is also interesting to note that the AMS applied to 3- to 4-leaf rice was incorporated as a starter fertilizer source only 4 days prior to flood establishment and preflood N incorporation, yet resulted in a 14.3 bu./ac grain yield advantage over the untreated check. The addition of DAP as a starter fertilizer source did not significantly increase grain yield at any of the application timings.

Ammonium sulfate at the 2-leaf growth stage also significantly increased head rice yield by 1.4% compared to no starter fertilizer application and numerically increased head rice yield at all three growth stages. The addition of DAP did not provide an increase in milling yield compared to the untreated check. Total rice yield was largely unaffected by starter fertilizer application, regardless of fertilizer source, and averaged from 70.2% to 71.4%. Canopy height was only significantly affected 3 weeks after application when starter fertilizer was applied at the 1-leaf growth stage and was increased by 2.4 and 1.7 cm by AMS and DAP, respectively (Table 1).

Practical Applications

The addition of AMS as a starter fertilizer source at 2-leaf and 3- to 4-leaf rice resulted in a significant increase in grain yield; however, DAP did not provide the same yield response and was much less effective at increasing grain yield over the untreated check. It is important to note that the incorporation of these starter fertilizer applications did not occur until 5 days after application, which likely allowed the rice growth stage to progress by one additional leaf at a minimum (i.e., from 2-leaf rice to 3- to 4-leaf rice). The main objective of this research was to revisit the starter fertilizer recommendation for direct-seeded, delayed-flood rice production on silt loam soils in Arkansas. Current University of Arkansas System Division of Agriculture recommendations are to forego starter fertilizer application altogether; however, results from this study suggest that AMS applied and incorporated between 3-leaf stage and preflood N application has the potential to increase rice grain yield. Grain yield was increased by 14.3–20.1 bu./ac, which would certainly pay for a 100 lb/ac AMS application excluding the possible increase in milling yield. Data is limited to one site-year, so it is imperative that more work be done on applying AMS during this time period to see if AMS application as a starter fertilizer could be a cost-effective practice for commercial rice production.

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Table 1. Mean rice grain yield, milling yield, and plant height at three weekly intervals after application of starter fertilizer trials applied to 1-leaf rice.

Starter Fertilizer Source	Rice Grain Yield	Head Rice†	Total Rice‡	Canopy Height Wk. 1	Canopy Height Wk. 2	Canopy Height Wk. 3
	(bu./ac)	--------------(%)--------------		--------------------(cm)--------------------		
None§	217.8	58.5	70.6	9.6	15.4	22.3 b¶
AMS	221.8	59.4	70.4	9.9	16.5	24.7 a
DAP	226.4	58.6	70.2	10.0	16.6	24.0 a
P-value	0.7188	0.3847	0.4448	0.1333	0.3653	0.0031

† Whole milled kernels.
‡ Total milled kernels.
§ None = no starter applied; AMS = ammonium sulfate; and DAP = diammonium phosphate.
¶ Means followed by the same letter within a column are not significantly different using a protected least significant difference at α = 0.10.

Table 2. Mean rice grain yield, milling yield, and plant height at three weekly intervals after application of starter fertilizer trials applied to 2-leaf rice.

Starter Fertilizer Source	Rice Grain Yield	Head Rice†	Total Rice‡	Canopy Height Wk. 1	Canopy Height Wk. 2	Canopy Height Wk. 3
	(bu./ac)	--------------(%)--------------		------------------(cm)------------------		
None§	172.4 b¶	62.1 b	71.3	11.4	20.1	29.8
AMS	192.5 a	63.5 a	71.4	12.4	21.6	30.0
DAP	179.4 b	62.5 ab	71.4	11.7	21.7	30.5
P-value	0.0183	0.0470	0.8067	0.3263	0.1740	0.1499

† Whole milled kernels.
‡ Total milled kernels.
§ None = no starter applied; AMS = ammonium sulfate; and DAP = diammonium phosphate.
¶ Means followed by the same letter within a column are not significantly different using a protected least significant difference at α = 0.10.

Table 3. Mean rice grain yield, milling yield, and plant height at three weekly intervals after application of starter fertilizer trials applied to 3- to 4-leaf rice.

Starter Fertilizer Source	Rice Grain Yield	Head Rice†	Total Rice‡	Canopy Height Wk. 1	Canopy Height Wk. 2	Canopy Height Wk. 3
	(bu./ac)	--------------(%)--------------		-------------------(cm)-------------------		
None§	205.1 b¶	62.5	71.3	15.9	32.8	48.5
AMS	219.4 a	63.1	70.9	16.9	34.2	49.6
DAP	213.1 ab	62.9	70.9	16.4	32.8	48.2
P-value	0.0851	0.4538	0.3221	0.1532	0.1608	0.2405

† Whole milled kernels.
‡ Total milled kernels.
§ None = no starter applied; AMS = ammonium sulfate; and DAP = diammonium phosphate.
¶ Means followed by the same letter within a column are not significantly different using a protected least significant difference at α = 0.10.

2020 Degree-Day 50 (DD50) Thermal Unit Thresholds for New Rice Cultivars and Seeding Date Studies

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Abstract

The Degree-Day 50 (DD50) rice management program is one of the most successful management aids developed by the University of Arkansas System Division of Agriculture. This program predicts critical growth stages that assist in increasing the effectiveness of crop management operations. In order to maintain its relevance, the computer program must be updated continually as new rice cultivars become available to growers. To accomplish this goal, studies are conducted in a controlled research environment where developmental data and DD50 thermal unit thresholds for current and new cultivars are determined. Throughout the 2020 season, DD50 thermal unit accumulation, developmental data, and the effect of seeding date (SD) on grain and milling yield potential for 20 cultivars were evaluated over 6 SDs under a dry-seeded, delayed-flood management system commonly used in southern U.S. rice production. Significant differences in grain and milling yield were observed for all 20 cultivars at each location.

Introduction

The Degree-Day 50 (DD50) is an outgrowth of the growing degree-day concept where daily high and low air temperatures are used to determine a day's thermal quality for plant growth. Conceived in the 1970s as a tool to time midseason nitrogen (N) applications, the DD50 computer program has grown into a management aid that provides predicted dates for timing over 26 key management decisions, including fertilization, pesticide applications, permanent flood establishment, times for scouting insect and disease, predicted draining date and suggested harvest time (Hardke et al., 2018).

Beginning at emergence, the DD50 (days with a minimum average temperature of at least one degree above 50 °F) generates a predicted, cultivar-specific, rice plant development file based on the accumulation of DD50 units calculated using the formula: DD50 = (Daily Maximum + Daily Minimum/2)-50, considering that Maximum temperature = 94 °F if the maximum temperature is >94 °F, and Minimum temperature = 70 °F if the minimum temperature is >70 °F. The growth stages predicted are: beginning optimum tillering, beginning internode elongation (BIE), 0.5-in. internode elongation (0.5-in. IE), 50% heading, drain date, and 20% grain moisture (Hardke et al., 2018). The initial file is created by calculating thermal unit accumulation using a 30-year average weather data set collected by the National Weather Service weather station closest to the rice producer's location in Arkansas. As the season progresses, the program is updated with the current year's weather data on a daily basis which improves accuracy.

The data used to predict plant development for a specific cultivar are generated in yearly studies where promising experimental lines and newly released conventional and hybrid rice cultivars are evaluated in four to six seeding dates (SDs) per season within the recommended range of rice SDs for Arkansas. Once a new cultivar is released, the information obtained in these studies is utilized to provide threshold DD50 thermal units to the DD50 computer program that enables the prediction of dates of plant developmental stage occurrences and predictions of suggested dates when particular management practices could be performed. Therefore, the objectives of this study were to develop a DD50 thermal accumulation database for promising new cultivars, verification and refinement of the existing database of current cultivars, and assessment of the effect of SD on DD50 thermal unit accumulation, and also effects of SD on grain and milling yields of a particular cultivar for the identification of optimal SDs.

Procedures

The 2020 DD50 seeding date studies were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. on a DeWitt silt loam soil, and the Pine Tree Research Station (PTRS) near Colt, Ark. on a Calloway silt loam soil. Twelve pure-line cultivars (ARoma 17, CLL15, CLL16, CLL17, CLM04, DG263L, Diamond, Jewel, Jupiter, LAX7-2140, Lynx, ProGold1, ProGold2, PVL02, and Titan) were drill-seeded at a rate of 36 seed/ft^2 in plots 8 rows wide (7.5-in. spacing) and 16.5 ft long, and 8 hybrids (RT XP753, RT 7301, RT 7321 FP, RT 7401, RT 7501, RT 7521 FP, and RT 7801) were seeded into plots of the same dimensions using the reduced seeding rate for hybrids (12.1 seeds/ft^2). The SDs for 2020 at RREC were 27 March, 6 April, 21 April, 6 May, 19 May, and 2 June, and at PTRS were 21 April, 6 May, 21 May, and 3 June. Standard cultural practices were fol-

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lowed according to the University of Arkansas System Division of Agriculture recommendations. A single preflood nitrogen (N) application of 130 lb N/ac was applied to all plots at RREC and 145 lb N/ac was applied to all plots at PTRS at the 4- to 6-leaf growth stage and flooded within 2 days of application. Data collected include maximum and minimum temperatures, date of seedling emergence, and the number of days and DD50 units required to reach 50% heading. The number of days and DD50 thermal units required to reach 0.5-in. IE was also collected for 27 March, 21 April, and 19 May at the RREC location. At maturity, the 4 center rows in each plot were harvested, the weight of grain and moisture content were recorded, and a subsample of harvested grain was taken for milling purposes on all SDs. The grain yield was adjusted to 12% moisture and reported on a bushel/ac (bu./ac) basis. The dry rice was milled to obtain data on the percent of head rice and the percent of total white rice (%HR/%TR). The study design was a randomized complete block with four replications for each SD. Statistical analysis was conducted using PROC GLM, SAS v. 9.4 (SAS Institute, Inc. Cary, N.C.) with means separation using Fisher's least significant difference test ($P = 0.05$).

Results and Discussion

The amount of time between seeding and emergence ranged from 6–15 days at the PTRS and 5–18 days at the RREC, directly affecting the required days from seeding to flooding (Tables 1 and 2). In general, SD studies report a decrease in days between seeding and emergence as the SD is delayed. The 2020 study followed this general trend of decreasing days from seeding to emergence as SD was delayed from late March to late May. The time from seeding to the establishment of permanent flood followed the same trend as the SD was delayed, ranging from 52 days for the 21 April to 34 for the 3 June SDs at PTRS and 56 days for the 27 March to 30 for the 2 June SDs at RREC. The times from emergence to flooding also follow the general trend of decreasing days with later SDs.

A decreasing trend in days and thermal units was observed to reach 0.5-in. IE from emergence as SD was delayed at RREC (Table 3) as was the case for 2019 (Clayton et al., 2020). The cultivars DG263L, LAX7-2140, and RT 7321 FP required the fewest days and DD50 units to reach 0.5-in. IE with 53, 57, and 57 days, respectively, and 1198, 1301, and 1280 DD50 units, respectively. The cultivars ARoma 17 and Lynx required the most days and DD50 units to reach 0.5-in. IE with 64 and 66 days respectively, and 1517 and 1570 DD50 units, respectively. The average days to 0.5-in. IE across planting dates was 60, and the average DD50 units across planting dates was 1378.

The average days needed to reach the developmental stage known as 50% heading from the time of emergence across SDs and cultivars was 85 days at the RREC and 81 days at the PTRS (Tables 4 and 5). The time for cultivars to reach 50% heading ranged from 75 to 103 days at the RREC and from 72 to 90 days at the PTRS across SDs. For individual cultivars, the time required to reach 50% heading ranged from 103 days for Jupiter and RT 7801 to 75 days for PVL02 and Titan at the RREC. For the PTRS, the days to 50% heading ranged from 90 days for CLL16 and RT 7801 to 71 days for DG263L. For 2020, the thermal unit accumulation from emergence to 50% heading averaged 2228 DD50 units at the RREC and 2337 DD50 units at the PTRS. The individual cultivar thermal unit accumulation from emergence to 50% heading ranged from 2048 DD50 units for RT 7321 FP to 2435 DD50 units for RT 7521 FP at the RREC. For the PTRS, thermal unit accumulation from emergence to 50% heading ranged from 2142 DD50 units for DG263L to 2504 DD50 units for ProGold2 and ProGold1. The lowest average thermal unit accumulation was the 6 April planting at the RREC and 3 June at the PTRS.

The average grain yield for 2020 at the RREC was 205 bu./ac and 190 bu./ac at the PTRS across SDs (Tables 6 and 7). The highest average grain yield across all cultivars was the 21 April SD at the RREC and the 6 May SD at the PTRS. DG263L was the highest yielding variety at both locations, and the hybrids RT 7501 and RT 7401 yielded the highest at the RREC and the PTRS, respectively.

The milling yields for 2020, averaged across SDs and cultivars, were 60/69 (%HR/%TR) at the RREC and 61/69 at the PTRS (Tables 8 and 9). The milling yields were consistent for all the SDs at both locations. This data is similar to 2019 (Clayton et al., 2020) but differs from 2018 when the milling yield at RREC decreased for the mid-May SD (Castaneda-Gonzalez et al., 2019).

Practical Applications

The data obtained during 2020 will be used to improve the DD50 thermal unit threshold for new cultivars and hybrids being grown. The grain and milling yield data contribute to the database of information used by Division personnel to help producers make decisions in regard to rice cultivar selection, in particular for early- and late-seeding situations.

Acknowledgments

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Table 1. General seeding, seedling emergence, and flooding date information for the Degree-Day 50 (DD50) seeding date study in 2020 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Arkansas.

	Seeding Date					
	27 March	**6 April**	**21 April**	**6 May**	**19 May**	**2 June**
Emergence date	9 April	24 April	4 May	15 May	24 May	9 June
Flood date	22 May	27 May	3 June	12 June	19 June	2 July
Days from seeding to emergence	13	18	13	8	5	7
Days from seeding to flooding	43	33	30	43	26	23
Days from emergence to flooding	56	51	43	34	31	30

Table 2. General seeding, seedling emergence, and flooding date information for the Degree-Day 50 (DD50) seeding date study in 2020 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, near Colt, Arkansas.

	Seeding Date			
	21 April	**6 May**	**21 May**	**3 June**
Emergence date	6 May	18 May	30 May	9 June
Flood date	12 June	18 June	2 July	7 July
Days from seeding to emergence	15	10	9	6
Days from seeding to flooding	37	42	33	28
Days from emergence to flooding	52	31	42	34

Table 3. Influence of seeding date on Degree-Day 50 (DD50) accumulations and days from emergence to 0.5-inch internode elongation of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Arkansas, during 2020.

	Seeding Date							
	27 March		21 April		6 May		Average	
Cultivar	days	DD50 units	Days	DD50 units	days	DD50 units	days	DD50 units
ARoma 17	78	1,541	62	1,518	53	1,493	64	1,517
CLL15	72	1,386	56	1,347	46	1,278	58	1,337
CLL16	73	1,386	56	1,347	48	1,330	59	1,354
CLL17	73	1,401	57	1,347	48	1,337	59	1,362
CLM04	76	1,494	61	1,496	53	1,393	63	1,461
DG263L	64	1,155	51	1,214	44	1,226	53	1,198
Diamond	75	1,445	59	1,427	50	1,399	61	1,424
Jewel	75	1,466	61	1,503	52	1,447	63	1,472
LAX7-2140	72	1,371	54	1,260	46	1,271	57	1,301
Lynx	80	1,583	63	1,555	56	1,571	66	1,570
ProGold1	74	1,431	59	1,424	49	1,369	61	1,408
ProGold2	76	1,480	60	1,434	51	1,415	62	1,443
PVL02	73	1,408	55	1,304	47	1,300	58	1,337
RT 7301	73	1,386	55	1,347	46	1,271	58	1,335
RT 7321FP	71	1,350	54	1,233	45	1,256	57	1,280
RT 7401	73	1,394	55	1,347	46	1,278	58	1,340
RT 7501	73	1,394	57	1,383	48	1,337	59	1,371
RT 7521FP	72	1,372	55	1,303	47	1,307	58	1,327
RT 7801	72	1,365	57	1,376	48	1,323	59	1,354
Mean	73	1,411	57	1,377	48	1,347	60	1,378
$LSD_{(\alpha = 0.05)}$[a]	2	49	1	46	1	36	NS[b]	38

[a] LSD = least significant difference.

[b] NS = not significant.

Table 4. Influence of seeding date on Degree-Day 50 (DD50) accumulations and days from emergence to 50% heading of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Arkansas, during 2020.

	Seeding Date													
	27 March		6 April		21 April		6 May		19 May		2 June		Average	
Cultivar	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units
ARoma 17	100	2,211	87	2,145	85	2,220	78	2,168	81	2,316	80	2,333	85	2,232
CLL15	99	2,164	86	2,113	84	2,190	79	2,213	80	2,292	78	2,280	84	2,209
CLL16	102	2,267	88	2,169	87	2,287	83	2,323	83	2,391	82	2,391	87	2,304
CLL17	99	2,165	86	2,113	84	2,205	79	2,198	78	2,244	79	2,303	84	2,205
CLM04	102	2,267	89	2,216	87	2,272	82	2,298	83	2,390	79	2,319	87	2,294
DG263L	97	2,095	86	2,113	83	2,168	76	2,101	76	2,176	78	2,287	83	2,156
Diamond	100	2,188	86	2,121	85	2,235	79	2,205	81	2,322	80	2,349	85	2,237
Jewel	101	2,243	86	2,121	87	2,272	81	2,269	82	2,353	82	2,383	86	2,273
Jupiter	103	2,291	90	2,238	86	2,250	81	2,257	82	2,359	80	2,341	87	2,289
LAX7-2140	101	2,235	85	2,090	83	2,175	78	2,161	78	2,244	80	2,339	84	2,207
Lynx	102	2,251	88	2,169	85	2,220	80	2,242	82	2,346	79	2,319	86	2,258
ProGold1	102	2,266	89	2,215	88	2,302	83	2,306	81	2,328	83	2,413	87	2,305
ProGold2	102	2,267	86	2,121	87	2,272	81	2,250	81	2,339	82	2,384	86	2,272
PVL02	98	2,125	86	2,113	83	2,168	76	2,108	76	2,173	75	2,177	82	2,144
RT 7301	98	2,133	86	2,113	84	2,197	77	2,153	77	2,212	78	2,280	83	2,181
RT 7321 FP	95	2,048	85	2,090	83	2,168	76	2,101	76	2,182	75	2,197	82	2,131
RT 7401	99	2,165	86	2,113	86	2,175	79	2,198	80	2,284	80	2,325	85	2,210
RT 7501	101	2,235	86	2,121	85	2,257	80	2,242	81	2,324	81	2,371	86	2,258
RT 7521FP	100	2,196	86	2,121	88	2,227	81	2,250	80	2,308	84	2,435	86	2,256
RT 7801	103	2,299	90	2,238	88	2,302	83	2,317	82	2,346	80	2,346	88	2,308
RT XP753	98	2,125	86	2,113	84	2,183	76	2,123	77	2,204	77	2,257	83	2,167
Titan	99	2,157	84	2,043	80	2,081	76	2,116	77	2,196	75	2,184	82	2,129
Mean	100	2,199	87	2,137	85	2,219	79	2,209	80	2,288	79	2,319	85	2,228
$LSD_{(\alpha = 0.05)}$[a]	2	55	1	32	1	32	1	36	2	46	2	58	NS[b]	42

[a] LSD = least significant difference.
[b] NS = not significant.

Table 5. Influence of seeding date on Degree-Day 50 (DD50) accumulations and days from emergence to 50% heading of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, near Colt, Arkansas, during 2020.

	Seeding Date									
	21 April		6 May		21 May		3 June		Average	
Cultivar	days	DD50 units	days	DD50 units	days	DD50 Units	days	DD50 Units	days	DD50 Units
ARoma 17	87	2,369	83	2,400	81	2,412	75	2,254	82	2,359
CLL15	87	2,369	83	2,400	79	2,362	74	2,225	81	2,339
CLL16	90	2,456	85	2,478	84	2,504	80	2,411	85	2,462
CLL17	86	2,340	78	2,274	77	2,302	74	2,225	79	2,285
CLM04	87	2,369	84	2,447	80	2,391	78	2,343	82	2,388
DG263L	83	2,244	78	2,274	77	2,302	71	2,142	77	2,241
Diamond	88	2,398	83	2,400	82	2,442	77	2,313	83	2,388
Jewel	89	2,427	84	2,423	83	2,462	78	2,343	84	2,414
Jupiter	86	2,340	82	2,379	80	2,391	77	2,313	81	2,356
LAX7-2140	86	2,340	80	2,333	77	2,302	74	2,225	79	2,300
Lynx	86	2,340	82	2,372	80	2,391	78	2,343	82	2,362
ProGold1	87	2,369	84	2,447	84	2,504	79	2,365	84	2,421
ProGold2	89	2,427	84	2,423	84	2,504	78	2,343	84	2,424
PVL02	86	2,340	79	2,300	77	2,302	73	2,204	79	2,287
RT 7301	86	2,340	78	2,274	77	2,302	73	2,204	79	2,280
RT 7321 FP	83	2,244	76	2,216	77	2,302	72	2,163	77	2,231
RT 7401	85	2,316	79	2,300	79	2,362	75	2,254	80	2,308
RT 7501	87	2,369	78	2,281	77	2,302	75	2,254	79	2,302
RT 7521FP	86	2,340	80	2,325	80	2,391	75	2,254	80	2,328
RT 7801	90	2,456	84	2,423	83	2,462	80	2,388	84	2,432
RT XP753	85	2,316	77	2,245	77	2,302	73	2,183	78	2,262
Titan	83	2,244	76	2,216	77	2,302	74	2,225	78	2,247
Mean	87	2,352	81	2,347	80	2,377	76	2,272	81	2,337
$LSD_{(\alpha=0.05)}$[a]	2	55	3	84	2	58	2	57	3	44

[a] LSD = least significant difference.

Table 6. Influence of seeding date on grain yield of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Arkansas, during 2020.

	Grain Yield by Seeding Date						
Cultivar	**27 March**	**6 April**	**21 April**	**6 May**	**19 May**	**2 June**	**Average**
	(bu./ac)						
ARoma 17	156	151	188	166	148	131	157
CLL15	219	202	229	207	173	123	192
CLL16	206	202	224	219	199	161	202
CLL17	212	200	191	205	163	139	185
CLM04	196	193	212	208	190	158	193
DG263L	237	256	266	253	232	196	240
Diamond	221	185	232	221	192	158	202
Jewel	193	182	216	206	180	146	187
Jupiter	194	163	213	193	190	165	186
LAX7-2140	197	180	209	199	169	150	184
Lynx	212	193	192	211	204	166	197
ProGold1	192	183	232	219	198	165	198
ProGold2	206	193	225	207	179	154	194
PVL02	182	160	131	192	143	138	158
RT 7301	244	217	255	245	210	198	228
RT 7321 FP	237	230	258	248	217	194	230
RT 7401	246	230	272	269	241	200	243
RT 7501	245	228	277	269	246	217	247
RT 7521 FP	244	234	241	248	208	174	225
RT 7801	226	209	262	252	245	195	232
RT XP753	251	225	273	254	232	194	238
Titan	218	188	223	185	156	155	188
Mean	215	200	228	222	196	167	205
$LSD_{(\alpha = 0.05)}$[a]	17	17	24	14	18	17	15

[a] LSD = least significant difference

Table 7. Influence of seeding date on grain yield of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, near Colt, Arkansas, during 2020.

	Grain Yield by Seeding Date				
Cultivar	**21 April**	**6 May**	**21 May**	**3 June**	**Average**
	----------(bu./ac)----------				
ARoma 17	175	179	153	139	162
CLL15	204	195	172	164	184
CLL16	201	210	171	160	186
CLL17	213	205	168	164	188
CLM04	212	216	151	146	181
DG263L	250	255	210	193	227
Diamond	174	210	155	156	174
Jewel	181	189	153	146	167
Jupiter	208	194	179	145	181
LAX7-2140	192	197	143	123	164
Lynx	230	221	179	149	195
ProGold1	203	207	162	157	182
ProGold2	174	188	155	139	164
PVL02	181	183	138	122	156
RT 7301	222	241	184	168	204
RT 7321 FP	234	250	167	170	205
RT 7401	243	265	216	197	231
RT 7501	236	246	204	190	219
RT 7521 FP	247	247	198	179	218
RT 7801	227	231	188	168	203
RT XP753	230	250	183	172	209
Titan	213	210	178	156	189
Mean	211	218	173	159	190
$LSD_{(\alpha = 0.05)}$ [a]	16	23	24	19	21

[a] LSD = least significant difference.

Table 8. Influence of seeding date on milling yield of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Arkansas, during 2020.

	Milling Yield by Seeding Date						
Cultivar	**27 March**	**6 April**	**21 April**	**6 May**	**19 May**	**2 June**	**Average**
	(%HR/%TR)[a]						
ARoma 17	65/71	66/71	64/71	63/70	60/69	60/68	63/70
CLL15	62/69	59/68	61/69	59/68	58/66	48/59	58/67
CLL16	60/69	59/68	57/68	57/68	54/66	59/67	58/68
CLL17	62/68	63/69	60/68	60/68	58/66	53/62	59/67
CLM04	65/68	65/68	64/69	62/67	63/67	62/66	64/67
DG263L	57/66	57/66	59/68	58/67	58/67	55/64	57/66
Diamond	61/71	58/69	58/69	56/69	55/66	61/68	58/69
Jewel	61/71	61/70	60/70	57/69	59/69	62/68	60/70
Jupiter	64/67	63/67	64/68	63/67	62/66	61/65	63/67
LAX7-2140	63/70	63/71	59/69	59/69	58/68	59/66	60/69
Lynx	62/67	62/67	62/68	59/67	62/67	58/63	61/67
ProGold1	63/71	62/70	59/69	56/68	58/68	65/70	61/69
ProGold2	62/71	57/70	58/70	52/69	57/69	61/68	58/70
PVL02	66/72	66/72	63/72	63/71	60/70	60/68	63/71
RT 7301	62/71	58/70	61/71	55/70	61/70	60/69	59/70
RT 7321 FP	57/70	52/69	57/70	57/70	61/69	58/66	57/69
RT 7401	60/70	59/71	59/70	58/70	59/69	61/68	59/70
RT 7501	62/71	61/70	60/70	58/70	60/70	63/70	61/70
RT 7521 FP	60/70	62/71	60/70	59/69	59/69	61/68	60/69
RT 7801	60/69	62/70	58/69	57/69	59/69	59/67	59/69
RT XP753	59/71	56/70	60/71	57/70	60/70	60/69	59/70
Titan	66/69	60/69	64/69	63/69	62/68	61/66	63/68
Mean	62/70	61/69	60/69	59/69	59/68	59/67	60/69
$LSD_{(\alpha = 0.05)}$ %HR[b]	2	2	2	2	2	2	1
$LSD_{(\alpha = 0.05)}$ %TR	1	1	1	1	1	2	1

[a] %HR/%TR = percent head rice/percent total rice.

[b] LSD = least significant difference.

Table 9. Influence of seeding date on milling yield of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, near Colt, Arkansas, during 2020.

	Milling Yield by Seeding Date				
Cultivar	**21 April**	**6 May**	**21 May**	**3 June**	**Average**
	------(%HR/%TR)[a]------				
ARoma17	67/71	66/71	64/70	61/68	65/70
CLL15	63/70	63/69	59/68	59/66	61/68
CLL16	61/69	59/68	59/69	57/67	59/68
CLL17	63/69	62/68	59/67	58/66	60/68
CLM04	66/69	66/69	63/68	62/66	64/68
DG263L	59/68	60/69	52/65	51/63	55/66
Diamond	58/69	62/70	61/70	61/69	61/69
Jewel	62/70	64/71	63/71	62/69	63/70
Jupiter	66/68	65/68	62/67	61/65	63/67
LAX7-2140	63/70	63/70	60/69	58/67	61/69
Lynx	63/70	64/69	61/68	61/66	62/68
ProGold1	60/70	64/70	63/71	61/69	62/70
ProGold2	56/70	62/71	62/71	61/69	60/70
PVL02	65/72	66/72	61/70	60/69	63/71
RT 7301	53/70	59/71	57/70	59/69	57/70
RT 7321 FP	57/70	58/71	55/69	54/68	56/69
RT 7401	60/70	61/71	60/70	60/69	61/70
RT 7501	60/70	62/71	59/70	59/68	60/70
RT 7521 FP	59/70	62/70	59/69	59/68	60/69
RT 7801	58/69	60/70	59/69	56/67	58/69
RT XP753	57/71	60/72	56/70	58/68	58/70
Titan	63/70	64/70	64/69	63/68	63/69
Mean	61/70	62/70	60/69	59/67	61/69
$LSD_{(\alpha = 0.05)}$ % HR[b]	3	3	2	2	2
$LSD_{(\alpha = 0.05)}$ % TR	1	1	1	2	1

[a] %HR/%TR = percent head rice/percent total rice.

[b] LSD = least significant difference.

Grain Yield Response of Ten Rice Cultivars to Seeding Rate

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Abstract

The cultivar × seeding rate studies determine the proper seeding rates for new rice (*Oryza sativa*, L.) cultivars over a range of production and growing conditions in Arkansas. The 10 rice cultivars evaluated in 2020 were: CLL15, CLL16, CLL17, CLM04, DG263L, Jewel, Lynx, ProGold1, ProGold2, and PVL02. The cultivars CLL15, CLM04, and PVL02 were evaluated beginning in 2019, and the other seven were new for 2020. Each cultivar was seeded at 10, 20, 30, 40, and 50 seed/ft^2. In accordance with current recommendations and predominant grower practice, all seeds received insecticide and fungicide seed treatments. Trials were seeded at 5 on-farm locations in eastern Arkansas. Due to space limitations, each location was seeded with either 5 conventional or herbicide-tolerant cultivars. Stand density and grain yield results were consistent with current seeding rate recommendations of 30 seed/ft^2 (65 to 80 lb/ac) under optimum conditions and seeding dates on silt loam soils and 36 seed/ft^2 on clay soils. It should be noted that without the use of insecticide and fungicide seed treatments, stand density and grain yield may be reduced compared to results in this study. At Greene County during 2020, the seeding rate significantly influenced the grain yield of Jewel and ProGold2 but not DG263L, ProGold1, or Lynx. At Phillips Co. on a clay soil, the seeding rate influenced the grain yield of the 4 cultivars harvested at this location during 2020. At both Lawrence Co. on a silt loam soil and Lonoke Co. on a clay soil, the seeding rate did not influence the grain yield for any of the 5 cultivars (CLL15, CLL16. CLL17, CLM04, and PVL02). At Poinsett Co. on a silt loam soil, the grain yield of only the cultivar CLL16 was influenced by the seeding rate. At Greene County during 2020, the seeding rate significantly influenced the stand density of Jewel, ProGold1, ProGold2, and Lynx but not DG263L. At Lawrence, Lonoke, and Poinsett Counties during 2020, seeding rates of 10 or 50 seed/ft^2 resulted in stand densities consistently below or above the recommended range, respectively, for all cultivars.

Introduction

Optimal rice (*Oryza sativa*, L.) stand density for pure-line cultivars is considered to be 10 to 20 plants/ft^2 (Hardke et al., 2018). Rice seeding rate is adjusted as needed to meet field-specific conditions, but generally 30 seed/ft^2 on silt loam soils and 36 seed/ft^2 on clay soils are adequate to obtain the desired stand density. The use of an insecticide seed treatment has been shown to increase stand density by over 10% and increase grain yield by an average of 8 bu./ac (Taillon et al., 2015). The use of insecticide seed treatments continues to increase each year, and they are currently used on approximately 80% of the rice acres in Arkansas (Hardke, 2019). Lower stand densities and grain yields may be expected when planting without the use of insecticide seed treatments.

The release of new cultivars, combined with changes in production practices, including the use of insecticide and fungicide seed treatments, requires the continued evaluation of seeding rates for new cultivars to ensure that the recommendations maximize the profit potential for rice growers. The objective of this study was to determine the optimal seeding rate to maximize grain yield for 10 new rice cultivars in environments and growing conditions common to Arkansas rice production.

Procedures

The 5 on-farm locations for the 2020 cultivar × seeding rate studies included a grower field in Greene Co. on a silt loam soil near Paragould, Arkansas; a grower field in Lawrence Co. on a silt loam soil near Walnut Ridge, Arkansas; a grower field in Lonoke Co. on a clay soil near England, Arkansas; a grower field in Phillips Co. on a clay soil near Lambrook, Arkansas; and a grower field in Poinsett Co. on a silt loam soil near Waldenburg, Arkansas. In order to maximize space in the grower's field, the cultivars were grouped according to herbicide tolerance. The pure-line herbicide-tolerant cultivars CLL15, CLL16, CLL17, CLM04, and PVL02 were seeded at Lawrence Co. on 7 May, Lonoke Co. on 4 May, and Poinsett Co. on 22 April. The pure-line conventional cultivars DG263L, Jewel, Lynx, ProGold1, and ProGold2 were seeded at Greene Co. on 10 April and Phillips Co. on 5 May. All seed was treated with CruiserMaxx Rice seed treatment (insecticide + fungicides) plus Vibrance fungicide and also Zinche® seed treatment containing 32.5% zinc oxide. Seeding rates evaluated for each cultivar were 10, 20, 30, 40, and 50 seed/ft^2. The midpoint of 30 seed/ft^2 corresponds to 65 to 80 lb seed/ac for most cultivars and is the base recommendation on well-prepared silt loam soils. Plots were 8 rows (7.5-in. spacing) wide and 16.5-ft in length. Cultural practices otherwise followed recommended practices for maximum yield. The experimental design for all trials and cultivars was a randomized complete block design with five replications.

Stand density was determined 3–4 weeks after rice emergence by counting the number of seedlings that emerged in 10 row ft. Nitrogen (N) was applied to studies at the 4- to 6-leaf

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growth stage in accordance with the grower's standard practice. At maturity, the center 4 rows of each plot were harvested, and the moisture content and weight of the grain were determined. Grain yields were adjusted to 12% moisture and reported on a bushels/acre (bu./ac) basis. A bushel of rice weighs 45 lbs. Data were analyzed using analysis of variance, PROC GLM, SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with means separated using Fisher's least significant difference test (P = 0.05).

Results and Discussion

During 2020, the stand density of each entry was influenced by the seeding rate at each location, with the exception of DG263L at Greene Co. Stand density data for Phillips Co. was not collected. The influence of seeding rate on grain yield was not as pronounced as the influence on stand density but was noted for several locations.

At Greene Co. on a silt loam soil, stand density of Jewel, ProGold2, and Lynx was highest-seeded at 40–50 seed/ft^2 and lowest-seeded at 10–20 seed/ft^2 (Table 1). Stand density of ProGold1 was highest-seeded at 50 seed/ft^2 and lowest-seeded at 10–20 seed/ft^2. Stand density of the 5 cultivars generally increased numerically as the seeding rate increased from 10 to 50 seed/ft^2. To reach a stand density within the recommended range of 10–20 plants/ft^2 at this location, all cultivars required a seeding rate of 30 seed/ft^2 or greater. The seeding rate significantly influenced the grain yield of Jewel and ProGold2, but not DG263L, ProGold1, or Lynx at this location during 2020. Grain yield of Jewel was highest when seeded at 30–50 seed/ft^2 and highest for ProGold2 when seeded at 20–50 seed/ft^2. It should be noted that overall stand densities at the Greene Co. site were lower due to prolonged periods of standing water prior to and following emergence.

At Phillips Co. on a clay soil, grain yield was highest for DG263L, ProGold1, and ProGold2 with seeding rates of 20–50 seed/ft^2 and Jewel when seeded at 40–50 seed/ft^2 (Table 2). Grain yield was lowest for each of the 4 cultivars when seeded at 10 seed/ft^2. Grain yield of Lynx was not reported at this location during 2020 due to lodging constraints at harvest.

At Lawrence Co. on a silt loam soil, stand density within each cultivar increased as the seeding rate increased from 10 to 50 seed/ft^2 (Table 3). Stand density within the recommended range of 10–20 plants/ft^2 was obtained using 20 seed/ft^2 for CLL15 and CLL16, and 20–30 seed/ft^2 for CLL17, CLM04, and PVL02. Seeding rates of 10 or 40–50 seed/ft^2 for each of the cultivars resulted in stand densities below or above the recommended range, respectively. Stand density did not influence grain yield for any of the five cultivars at this location during 2020.

At Lonoke Co. on a clay soil, the stand density for each of the 5 cultivars was lowest when seeded at 10 seed/ft^2. Stand density was highest in CLL15, CLM04, and PVL02 when seeded at 40–50 seed/ft^2 and highest for CLL16 and CLL17 when seeded at 50 seed/ft^2 (Table 4). Stand density within the recommended range of 10–20 plants/ft^2 was obtained using 20–30 seed/ft^2 for CLL15, CLL16, CLM04, and PVL02 and 20–40 seed/ft^2 for CLL17. Stand density did not influence grain yield for any of the 5 cultivars at this location during 2020.

At Poinsett Co. on a silt loam soil, stand density was maximized using seeding rates of 50 seed/ft^2 for CLL15, CLL16, CLL17, and CLM04, and 40–50 seed/ft^2 for PVL02 (Table 5). Stand density was also lowest for the Clearfield lines when seeded at 10 seed/ft^2 and for the Provisia line when seeded at 10–20 seed/ft^2. The recommended stand density range of 10–20 plants/ft^2 was obtained for CLL15, CLL17, and CLM04 seeded at 20 seed/ft^2 and 20–30 seed/ft^2 for CLL16 and PVL02 during 2020. Grain yield of CLL16 was highest-seeded at 20–50 seed/ft^2 and lowest-seeded at 10 seed/ft^2. Stand density did not influence the grain yield of the other cultivars at this location during 2020.

Comparisons of grain yields of the cultivars DG263L, Jewel, ProGold1, ProGold2, and Lynx at Greene and Phillips counties by converting to percent of optimal yield are provided in Fig. 1. At Greene Co., DG263L grain yield was maximized at the 50 seed/ft^2 seeding rate, and greater than 95% optimal grain yield was obtained with a seeding rate of 30–50 seed/ft^2. Jewel grain yield was maximized at 50 seed/ft^2, and greater than 95% optimal grain yield was obtained using 40–50 seed/ft^2. Maximum grain yield for ProGold1 at this location was obtained at 50 seed/ft^2, which was also the only seeding rate resulting in 95% optimal grain yield during this study year. ProGold2 grain yield was maximized at the 50 seed/ft^2 seeding rate, and seeding rates of 40–50 seed/ft^2 resulted in greater than 95% optimal grain yield. Maximized grain yield of Lynx was obtained at 10 seed/ft^2, and greater than 95% optimal grain yield was obtained with a seeding rate of 10–30 seed/ft^2.

At Phillips Co. during 2020, the grain yield of DG263L was maximized at seeding rates of 20 and 50 seed/ft^2. The range of 20–50 seed/ft^2 produced greater than 95% optimal grain yield. The grain yield of Jewel was maximized using a seeding rate of 50 seed/ft^2, which was also the only seeding rate that resulted in greater than 95% optimal grain yield. ProGold1 maximized grain yield was noted using 40 seed/ft^2, and greater than 95% optimal grain yield was obtained using a seeding rate of 20–50 seed/ft^2. Maximized grain yield of ProGold2 at this location was noted at seeding rates of 20 or 50 seed/ft^2, and 95% or greater optimal grain yield was obtained by seeding in the range of 20–50 seed/ft^2.

With the exception of Lynx at Greene Co., the lower seeding rate of 10 seed/ft^2 resulted in less than 95% optimal grain yield at both Greene and Phillips Co. during 2020. These two locations generally required 30–50 seed/ft^2 to achieve 95% optimal grain yield. The study location at Greene Co. also generally required 30–50 seed/ft^2 to provide a stand density within the recommended range for 4 of the cultivars. Although stand density was not different for DG263L, a seeding rate of 50 seed/ft^2 was needed to produce stand density within the recommended range at Greene Co. during 2020.

Comparisons of optimal grain yield of CLL15, CLL16, CLL17, CLM04, and PVL02 seeded at Lawrence, Lonoke, and Poinsett counties during 2020 are provided in Fig. 2. At Lawrence Co. during 2020, grain yield was maximized for CLL15 at 30 seed/ft^2 and greater than 95% optimal grain yield was obtained using 10 or 30–50 seed/ft^2. Grain yield was maximized for CLL16 at a seeding rate of 30 seed/ft^2 and greater than 95% optimal grain yield was noted at seeding rates of 10 and 30–40 seed/ft^2. Maximized grain yield of CLL17 was obtained using 30 seed/ft^2 and 95% or greater optimal grain yield was obtained using seeding rates of 10–40 seed/ft^2. The maximized grain yield of CLM04 was noted when seeded at 40–50 seed/ft^2 and optimal grain yield of greater than 95% was obtained using seeding rates of 20–50 seed/ft^2. Grain yield of PVL02 was maximized at 20 seed/ft^2 and greater than 95% optimal grain yield was observed at seeding rates of 10–20 and 40 seed/ft^2.

At Lonoke Co., seeding rates of 30, 40, 10, 20, and 20 seed/ft^2 maximized grain yield for CLL15, CLL16, CLL17, and CLM04 and PVL02, respectively. Greater than 95% optimal grain yield was obtained using seeding rates 30–50 seed/ft^2 for CLL15, 20–50 seed/ft^2 for CLL16, and 10–40 seed/ft^2 for CLL17. The cultivar CLM04 required a seeding rate of 10–20 seed/ft^2 to obtain 95% or greater optimal grain yield and PVL02 maintained greater than 95% optimal grain yield with all seeding rates with the exception of 40 seed/ft^2.

At Poinsett Co., CLL15 maximized grain yield at 10 seed/ft^2 and maintained greater than 95% optimal grain yield across all seeding rates. The grain yield of CLL16 was maximized at a seeding rate of 50 seed/ft^2, and the seeding rates needed to maintain 95% or greater optimal grain yield ranged from 20–50 seed/ft^2. The cultivar CLL17 required a seeding rate of 40 seed/ft^2 to maximize grain yield and seeding rates of 20–50 seed/ft^2 resulted in 95% or greater optimal grain yield. The cultivar CLM04 maximized grain yield at 30 seed/ft^2, and 95% optimal grain yield was obtained for this cultivar when seeding at 30–50 seed/ft^2. Maximized grain yield of PVL02 was noted at a seeding rate of 20 seed/ft^2 and seeding rates of 20–50 seed/ft^2 produced 95% optimal grain yield during 2020.

For the study locations at Lawrence, Lonoke, and Poinsett Cos. during 2020, greater than 95% optimal grain was noted for a range of seeding rates for each cultivar at each location. An optimal grain yield of greater than 95% was noted for a few of the cultivars when seeded at 10 seed/ft^2. However, this seeding rate did not produce a recommended stand density of 10–20 plants/ft^2 for any of the five cultivars at these locations.

Practical Applications

The cultivar × seeding rate studies in 2020 agree with previous research that an optimum seeding rate for new rice cultivars grown within the recommended planting window for a given location is approximately 30 seed/ft^2 on a silt loam soil and a well-prepared seedbed and approximately 36 seed/ft^2 on a clay soil and a well-prepared seedbed. Seeding rates lower than the current recommendation may produce a desirable grain yield if all conditions are favorable but risk insufficient stand densities that will be unable to maximize grain yield potential if unfavorable conditions occur within the growing season. However, seeding rates greater than the baseline recommendation of 30 seed/ft^2 on silt loam soils and 36 seed/ft^2 on clay soils risk the potential for stand density greater than the recommended 10–20 plants/ft^2, which could contribute to increased disease pressure or lodging. The findings from this study are based on results from silt loam and clay soils and currently recommended seeding rate adjustments based on soil type and seeding date. Environmental conditions and individual field history should be taken into consideration when determining seeding rates outside of these study conditions.

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Table 1. Influence of seeding rate on stand density and grain yield at Greene County during 2020 (seeded 10 April; harvested 15 September).†

Seeding	Stand Density					Grain Yield				
Rate	DG263L	Jewel	ProGold1	ProGold2	Lynx	DG263L	Jewel	ProGold1	ProGold2	Lynx
($seed/ft^2$)	---(plants/ft^2)---					---(bu./ac)---				
10	3.3	5.1 d‡	4.5 c	4.6 d	4.8 c	180.1	104.9 c	130.9	145.2 b	205.6
20	5.1	6.9 cd	7.1 bc	9.4 cd	7.6 c	199.3	129.6 b	152.9	171.1 ab	204.1[12#]
30	9.4	10.4 bc	9.6 b	11.2 bc	9.2 bc	218.2	131.6 ab	158.5	183.0 a	197.7
40	9.1	16.4 a	7.0 bc	15.2 ab	13.0 ab	219.2	148.6 ab	160.8	189.3 a	178.6
50	11.0	13.6 ab	15.0 a	20.3 a	17.3 a	223.2	153.2 a	179.1	194.3 a	172.7
$LSD_{0.05}$§	NS¶	5.0	3.8	5.4	4.8	NS	23.6	NS	26.1	NS

† Farmer field near Paragould, Arkansas, on a silt loam soil.
‡ Means within a column followed by the same letter are not significantly different ($P > 0.05$).
§ LSD = least significant difference.
¶ NS = not significant.
# Numbers in superscript to the side of the grain yield are lodging percentages.

Table 2. Influence of seeding rate on grain yield at Phillips County during 2020 (seeded 5 May; harvested 5 October).†

Seeding	Grain Yield			
Rate	DG263L	Jewel	ProGold1	ProGold2
($seed/ft^2$)	---(bu./ac)---			
10	188.0 b‡	166.9 d	178.0 b	188.0 b
20	218.7 a[75#]	181.5 c	195.5 a	218.7 a
30	209.5 a[68]	188.5 bc	202.5 a	209.5 a
40	211.7 a[100]	199.0 ab	204.7 a	211.7 a
50	219.0 a[100]	212.0 a	203.5 a	219.0 a[18]
$LSD_{0.05}$§	20.4	13.5	15.4	20.4

† Farmer field near Lambrook, Arkansas, on a clay soil.
‡ Means within a column followed by the same letter are not significantly different ($P > 0.05$).
§ LSD = least significant difference.
# Numbers in superscript to the side of the grain yield are lodging percentages.

Table 3. Influence of seeding rate on stand density and grain yield at Lawrence County during 2020 (seeded 7 May; harvested 7 October).[†]

Seeding	Stand Density					Grain Yield[§]				
Rate	CLL15	CLL16	CLL17	CLM04	PVL02	CLL15	CLL16	CLL17	CLM04	PVL02
(seed/ft^2)	(plants/ft^2)					(bu./ac)				
10	8.4 e[‡]	7.4 e	7.0 c	7.1 d	7.5 d	203.6	217.7	190.8	205.0	139.8^{40}
20	13.3 d	12.4 d	12.6 b	12.3 c	12.3 c	193.3	212.8	194.5^{6}	214.8	146.3^{62}
30	20.5 c	20.4 c	15.8 b	18.9 b	19.1 b	205.2	227.6	200.0^{16}	213.9^{8}	131.2^{88}
40	23.9 b	26.2 b	22.2 a	27.5 a	23.6 a	204.6	220.0	193.9^{20}	219.1^{20}	143.6^{90}
50	30.8 a	30.7 a	25.8 a	28.4 a	27.2 a	197.2	215.1	183.9^{40}	218.9^{20}	132.6^{72}
$LSD_{0.05}$[¶]	2.8	3.9	3.7	3.6	4.4	NS[#]	NS[#]	NS[#]	NS[#]	NS[#]

[†] Farmer field near Walnut Ridge, Arkansas, on a silt loam soil.
[‡] Means within a column followed by the same letter are not significantly different ($P > 0.05$).
[§] Numbers in superscript to the side of the grain yield are lodging percentages.
[¶] LSD = least significant difference.
[#] NS = not significant.

Table 4. Influence of seeding rate on stand density and grain yield at Lonoke County during 2020 (seeded 4 May; harvested 8 September).[†]

Seeding	Stand Density					Grain Yield				
Rate	CLL15	CLL16	CLL17	CLM04	PVL02	CLL15	CLL16	CLL17	CLM04	PVL02
(seed/ft^2)	(plants/ft^2)					(bu./ac)				
10	6.6 d[‡]	6.5 e	5.9 e	6.5 d	7.3 d	205.9	197.0	198.1^{73}	195.0^{2}	143.9^{100}
20	11.6 d	11.9 d	11.9 d	10.6 c	13.5 c	208.4	209.4	192.2^{75}	198.9^{4}	$150.0^{99.6}$
30	17.1 b	18.5 c	15.3 c	15.6 b	17.7 b	220.7^{2}[#]	212.7	190.2^{70}	187.8^{27}	146.3^{100}
40	21.7 a	22.1 b	18.4 b	20.4 a	24.3 a	217.5	216.2	191.5^{76}	185.6^{12}	132.3^{100}
50	24.3 a	24.7 a	24.1 a	21.7 a	26.2 a	217.2	211.5^{2}	$171.4^{97.5}$	181.4^{20}	145.7^{100}
$LSD_{0.05}$[§]	3.1	2.3	3.0	3.4	2.2	NS[¶]	NS[¶]	NS[¶]	NS[¶]	NS[¶]

[†] Farmer field near England, Arkansas, on a clay soil.
[‡] Means within a column followed by the same letter are not significantly different ($P > 0.05$).
[§] LSD = least significant difference.
[¶] NS = not significant.
[#] Numbers in superscript to the side of the grain yield are lodging percentages.

Table 5. Influence of seeding rate on stand density and grain yield at Poinsett County during 2020 (seeded 22 April; harvested 21 September).[†]

Seeding	Stand Density					Grain Yield				
Rate	CLL15	CLL16	CLL17	CLM04	PVL02	CLL15	CLL16	CLL17	CLM04	PVL02
(seed/ft^2)	(plants/ft^2)					(bu./ac)				
10	7.5 e[‡]	7.2 e	7.2 d	7.5 e	7.1 c	200.1	203.7 b	189.0	207.9	144.1
20	15.4 d	12.0 d	15.1 c	14.2 d	11.7 bc	193.2	216.2 a	195.9	206.8	155.3
30	23.3 c	18.0 c	21.7 b	21.1 c	19.0 ab	199.1	219.2 a	198.2	219.3	154.5
40	32.0 b	26.8 b	23.2 b	27.8 b	25.7 a	191.8	216.8 a	199.3	214.7	154.3
50	37.2 a	34.3 a	30.9 a	42.1 a	25.7 a	191.4	223.1 a	197.5	217.1	148.3
$LSD_{0.05}$[§]	4.5	4.6	3.3	6.0	8.8	NS[¶]	12.0	NS[¶]	NS[¶]	NS[¶]

[†] Farmer field near Waldenburg, Arkansas, on a silt loam soil.
[‡] Means within a column followed by the same letter are not significantly different ($P > 0.05$).
[§] LSD = least significant difference.
[¶] NS = not significant.

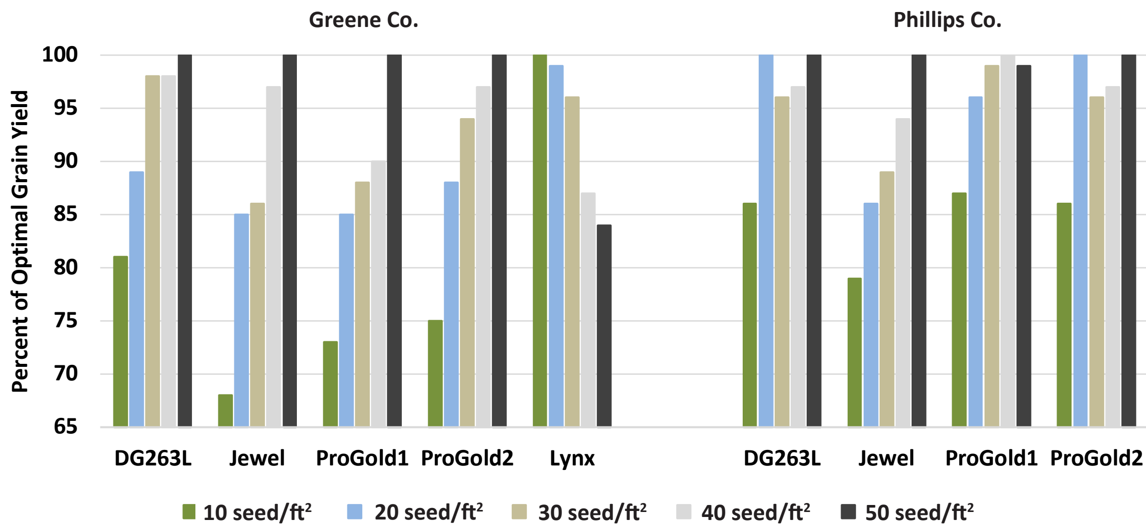

Fig. 1. Influence of seeding rate on rice grain yield in on-farm seeding rate trials of DG263L, Jewel, ProGold1, ProGold2, and Lynx in Greene and Phillips Counties during 2020. The percent of optimal grain yield is calculated based on the highest grain yield for each cultivar at each location equivalent to 100% optimal grain yield.

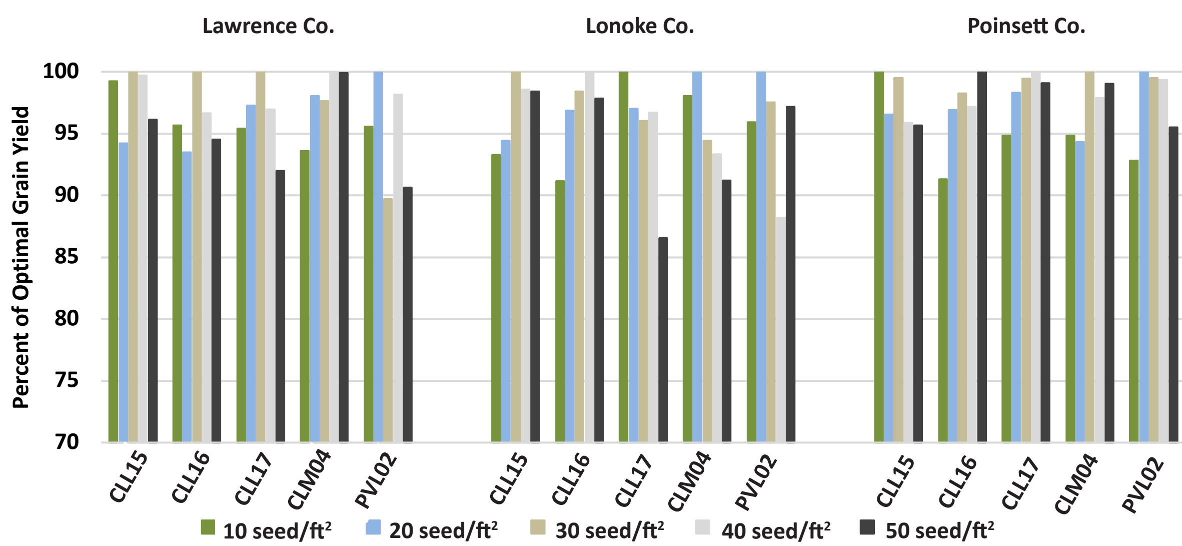

Fig. 2. Influence of seeding rate on rice grain yield in on-farm seeding rate trials of CLL15, CLL16, CLL17, CLM04, and PVL02 in Lawrence, Lonoke, and Poinsett Counties during 2020. The percent of optimal grain yield is calculated based on the highest grain yield for each cultivar at each location equivalent to 100% optimal grain yield.

Arkansas Rice Performance Trials, 2020

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Abstract

The Arkansas Rice Performance Trials (ARPTs) are conducted each year to evaluate promising experimental lines from the Arkansas rice breeding program compared with commercially available cultivars from public and private breeding programs. ARPTs are planted on experiment stations and cooperating producer's fields in a diverse range of environments, soil types, and agronomic and pest conditions. The ARPTs were conducted at 5 locations during 2020. Averaged across locations, grain yields were highest for RT XP753, RT 7521 FP, RU1901033, RU2001093, RU2001185, and RU1901129.

Introduction

The Arkansas Rice Performance Trials (ARPTs) are conducted each year to compare promising new experimental lines from the Arkansas rice breeding program with established cultivars currently grown in Arkansas. Multiple locations each year allow for continued reassessment of the performance and adaptability of advanced breeding lines and commercially available cultivars to such factors as environmental conditions, soil properties, and management practices. Data from the ARPTs is used by rice breeders to make release decisions on advanced experimental lines.

Procedures

The 5 locations for the 2020 ARPTs included the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas; the Pine Tree Research Station (PTRS) near Colt, Arkansas; the Northeast Research and Extension Center (NEREC) near Keiser, Arkansas; the Trey Bowers farm in Clay County (CLAY) near McDougal, Arkansas; and the Jim Whitaker farm in Desha County (DESHA) near McGehee, Arkansas. Fifty-nine entries, including established cultivars and promising breeding lines, were grown across a range of maturities.

The studies were seeded at RREC, PTRS, NEREC, DESHA, and CLAY on 6 April, 21 April, 21 May, 4 May, and 9 April, respectively. Pure-line cultivars (varieties) were drill-seeded at a rate of 36 seed/ft^2 in plots 8 rows (7.5-in. spacing) wide and 16.5-ft in length. Hybrid cultivars were drill-seeded into the same plot configuration using a seeding rate of 12 seed/ft^2. Cultural practices varied somewhat among the ARPT locations but overall were grown under conditions for high yield. Phosphorus (P) and potassium (K) fertilizers were applied before seeding at the RREC and PTRS locations. PTRS also received an application of zinc. Nitrogen (N) was applied to ARPT studies located on experiment stations at the 4- to 6-leaf growth stage in a single preflood application of 130 lb N/ac at RREC and 145 lbs N/ac at PTRS on silt loam soils, and 160 lb N/ac at NEREC on a clay soil using urea as the N source. The permanent flood was applied within 2 days of preflood N application and maintained throughout the growing season. Trials conducted in commercial fields were managed by the grower with the rest of the field in regard to fertilization, irrigation, and weed and insect control, but in most cases did not receive a fungicide application. If a fungicide was applied, it was considered in the disease ratings. Plots were inspected periodically and rated for disease. Percent lodging notes were taken immediately prior to harvest. At maturity, the center 4 rows of each plot were harvested, the moisture content and weight of the grain were determined, and a subsample of the harvested grain was removed for grain quality and milling determinations. Grain yields were adjusted to 12% moisture and reported on a bushels per acre (bu./ac) basis. The dried rice was milled to obtain percent head rice (%HR; whole kernels) and percent total white rice (%TR) presented as %HR / %TR. Each location of the study was arranged in a randomized complete block design with 4 replications.

Results and Discussion

The 5 ARPT locations in 2020 varied in overall performance (Table 1). Planting date and location within the state appeared to play

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critical roles in results at each location. The NEREC and DESHA locations averaged the shortest time to 50% heading, while RREC and PTRS averaged the longest time, with Clay in between the other 4 locations. Canopy height was greatest at the DESHA location, along with percent lodging. CLAY had the highest overall grain yields, followed by DESHA, NEREC, PTRS, and RREC, respectively. Head rice yields were highest at RREC, followed by NEREC, PTRS, CLAY, and DESHA, respectively.

Selected agronomic traits, grain yield, and milling yields from the 2020 ARPT are shown in Table 2. Nineteen experimental lines and 2 checks were included in the 2020 conventional long-grain ARPT. The checks Diamond and RT XP753 averaged 208 bu./ac and 239 bu./ac, respectively. The experimental line RU2001185 averaged 210 bu./ac, slightly better than the Diamond check. In addition, RU2001185 had an average milling yield of 61/71 (%HR/%TR) compared to Diamond (60/70).

Nineteen experimental lines and 4 checks were included in the 2020 Clearfield long-grain ARPT. The checks CLL15, CLL16, PVL02, and RT 7521 FP averaged 200, 205, 155, and 226 bu./ac, respectively. The experimental line RU2001093 averaged 217 bu./ac, notably higher than CLL15 and CLL16. The milling yield for RU2001093 was also similar to CLL15 and CLL16 at 59/69. Two other notable lines, RU1901129 and RU2001185, averaged 208 and 207 bu./ac, respectively, and also had milling yields of 65/71 and 62/71.

Four experimental lines and 1 check were included in the 2020 aromatic long-grain ARPT. The check ARoma 17 averaged 167 bu./ac., RU1901206 averaged 180 bu./ac, and RU1901231 averaged 167 bu./ac. ARoma 17 had an average milling yield of 65/71 compared to 61/69 and 64/71 for RU1901206 and RU1901231, respectively.

Eight experimental lines and 2 checks were included in the 2020 medium-grain and Clearfield medium-grain ARPT. The checks Titan and CLM04 averaged 199 and 192 bu./ac, respectively. The conventional medium-grain line RU1901033 averaged 225 bu./ac, higher than any medium-grain tested. The conventional medium-grain line RU1801237 (202 bu./ac) also out-yielded the Titan check. These 2 experimental lines, RU1901033 and RU1801237, had milling yields of 66/71 and 66/70, respectively, compared to 64/70 for Titan. The 3 Clearfield experimental lines, RU1801238, RU1901137, and RU1901169, averaged 208, 208, and 207 bu./ac., respectively, which were all greater than the CLM04 check. All three of these lines produced similar milling yields compared to the CLM04 check.

Practical Applications

Data from this study will assist the Arkansas rice breeding program in selecting lines for further advancement toward commercial release to Arkansas rice producers.

Acknowledgments

The authors wish to thank all Arkansas rice growers for financial support of the Arkansas Rice Performance Trials through the Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board. We also appreciate the support from the University of Arkansas System Division of Agriculture.

Table 1. Agronomic traits, grain yield, and milling yield in the Arkansas Rice Performance Trials (ARPT) by location in 2020.

Location	50% Heading[a]	Canopy Height	Harvest Moisture	Test Weight	Lodging	Grain Yield	Head Rice	Total Rice
	Days	Inches	%	lb/bu.	%	bu./ac	%	%
Clay[b]	83.0	34.6	11.4	43.8	0.9	242.8	61.1	71.0
Desha	78.0	42.9	13.0	41.4	9.8	198.5	60.4	69.4
NEREC	75.0	36.6	14.2	42.0	1.1	186.5	62.5	70.0
PTRS	89.1	34.7	14.6	41.0	0.1	181.1	62.4	70.6
RREC	88.2	33.9	18.0	38.8	0.0	170.5	63.8	70.6
$LSD_{(\alpha = 0.05)}$[c]	0.28	0.32	0.15	0.12	1.7	2.6	0.3	0.2
C.V.[d]	1.9	4.7	5.9	1.6	385.2	7.3	2.8	1.5

[a] 50% heading.

[b] Clay = Clay County; Desha = Desha County; NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[c] LSD = least significant difference.

[d] C.V. = coefficient of variation.

Table 2. Results of the Arkansas Rice Performance Trials at five locations during 2020.

Cultivar	Grain length[a]	Straw Strength[b]	50% heading[c]	Plant height	Test weight	Milling yield[d]	Grain yield by location and seeding date					
							CLAY	DESHA	NEREC	PTRS	RREC	MEAN
			(days)	(in.)	(lb/bu.)	(%HR/%TR)	--------------------------(bu./acre)--------------------------					
RU1601010	L	1.0	81	38.6	41.9	61/71	262	205	198	188	171	205
RU1901177	L	1.0	84	36.2	41.1	61/70	267	219	177	172	162	199
RU1902212	L	1.0	79	32.2	41.9	64/70	241	207	192	199	199	208
RU2001141	L	1.0	84	37.8	40.6	62/71	244	205	176	155	139	184
RU2001145	L	1.0	84	37.5	40.8	61/70	256	225	193	176	168	204
RU2001149	L	1.0	84	37.9	41.0	64/71	262	214	183	160	166	197
RU2001153	L	1.0	83	38.2	41.3	61/70	271	227	181	182	162	204
RU2001177	L	1.0	86	36.8	40.9	64/70	252	215	198	174	162	200
RU2001181	L	1.0	86	36.9	40.5	62/71	246	214	184	162	150	191
RU2001226	L	1.0	88	38.2	39.8	61/71	234	208	165	161	136	181
RU2001125	L	1.0	82	37.4	41.8	60/70	247	230	200	183	168	206
RU2001169	L	1.0	83	37.5	41.3	58/70	253	208	210	181	165	203
RU2001185	L	1.0	81	37.7	41.8	61/71	270	208	188	205	179	210
STG18P-01-231	L	1.0	84	36.7	41.4	62/71	234	218	160	154	138	181
STG17-L-16-215	L	1.0	87	39.0	39.8	59/69	228	210	145	134	127	169
Diamond	L	1.0	83	37.0	41.3	60/70	270	226	190	183	169	208
05X185	LH	1.0	82	42.1	41.1	58/70	196	187	170	174	153	176
RU2001211	LH	3.0	80	40.6	41.1	56/70	214	138	166	196	173	177
XH129	LH	1.0	78	38.5	41.8	48/68	242	193	210	195	164	201
H-19-357	LH	1.0	77	43.3	41.2	58/71	192	170	173	152	128	163
RT XP753	LH	1.0	80	38.0	42.8	60/72	290	263	219	225	196	239
RU1701090	CL	1.0	83	36.5	41.4	57/70	252	199	181	167	175	195
RU1702183	CL	1.0	79	31.7	42.7	63/70	232	204	177	183	186	197
RU1801101	CL	1.2	82	34.5	41.9	63/70	238	182	193	199	207	204
RU1801145	CL	1.2	83	38.6	41.6	61/70	255	210	203	184	170	204
RU1801169	CL	1.0	84	35.1	41.2	63/70	248	213	196	183	178	204
RU1901081	CL	1.0	84	38.4	41.1	63/71	248	218	192	175	189	204
RU1901129	CL	1.0	81	34.7	41.5	65/71	247	209	189	206	187	208

Continued

Table 2. Continued.

Cultivar	Grain length[a]	Straw Strength[b]	50% heading[c]	Plant height	Test weight	Milling yield[d]	Grain yield by location and seeding date					
							CLAY	DESHA	NEREC	PTRS	RREC	MEAN
			(days)	(in.)	(lb/bu.)	(%HR/%TR)	----------(bu./acre)----------					
RU1901173	CL	1.8	80	36.0	42.4	61/69	246	123	190	184	189	186
RU1902026	CL	1.2	80	33.0	42.7	61/70	256	189	189	201	202	207
RU2001081	CL	1.0	84	38.2	41.8	63/72	257	207	190	173	179	201
RU2001085	CL	1.0	82	36.5	41.1	62/71	264	217	193	185	173	207
RU2001073	CL	1.0	84	37.3	40.9	65/71	226	199	172	174	158	186
RU2001089	CL	1.0	84	40.1	41.6	65/71	251	201	190	172	181	199
RU2001093	CL	1.0	82	37.1	41.4	59/69	260	227	212	197	186	217
RU2001193	CL	1.0	82	33.3	41.4	61/69	229	194	186	177	181	193
RU2001201	CL	1.0	83	32.9	41.2	61/69	243	191	185	181	188	198
RU2001101	CL	1.6	82	39.4	42.1	62/72	253	120	202	186	179	188
RU2001121	CL	1.0	82	34.0	41.5	65/72	235	222	195	191	181	205
RU2001129	CL	1.0	82	32.8	41.4	63/71	245	228	172	190	181	203
CLL15	CL	1.0	81	32.7	41.9	61/69	238	183	191	190	199	200
CLL16	CL	1.2	85	37.9	40.6	59/69	257	205	203	185	178	205
PVL02	PL	2.6	80	37.0	42.3	64/71	151	94	168	185	181	155
RT 7521 FP	FLH	2.6	81	39.6	42.3	61/71	261	211	212	249	196	226
RU1901189	LA	1.6	83	36.1	41.1	65/71	213	152	161	150	143	164
RU1901206	LA	1.0	84	33.4	41.5	61/69	227	182	161	161	166	180
RU1901231	LA	1.0	82	38.8	41.5	64/71	214	176	171	153	122	167
RU2001105	LA	1.6	84	37.8	40.3	61/70	220	128	156	141	125	154
ARoma 17	LA	1.4	82	36.3	41.3	65/71	217	154	163	156	145	167
RU1801238	CM	1.4	83	37.0	41.8	65/71	250	199	208	196	184	208
RU1901137	CM	1.0	87	34.4	41.1	64/70	241	221	191	196	190	208
RU1901169	CM	1.2	83	36.3	41.6	64/70	265	203	194	180	192	207
CLM04	CM	1.6	85	38.0	41.0	66/70	235	163	192	194	175	192
RU1701127	M	1.0	84	34.0	40.2	66/69	232	205	202	164	148	190
RU1801237	M	1.0	84	33.1	40.5	66/70	250	208	189	193	169	202

Continued

Table 2. Continued.

Cultivar	Grain length[a]	Straw Strength[b]	50% heading[c]	Plant height	Test weight	Milling yield[d]	Grain yield by location and seeding date					
							CLAY	DESHA	NEREC	PTRS	RREC	MEAN
			(days)	(in.)	(lb/bu.)	(%HR/%TR)	---------------------------(bu./acre)---------------------------					
RU1901033	M	1.0	81	33.9	42.2	66/71	274	231	207	218	197	225
RU2001133	M	1.0	85	34.1	40.6	66/69	234	208	187	181	151	192
RU2001221	M	1.0	82	33.1	41.8	67/70	244	214	167	182	176	197
Titan	M	1.0	78	34.8	42.0	64/70	251	191	190	190	174	199
Mean		**1.2**	**83**	**36.3**	**41.0**	**62/70**	**230**	**189**	**177**	**171**	**161**	**186**

[a] Grain Type: L = long-grain; M = medium-grain; CL = Clearfield long-grain; CM = Clearfield medium-grain; PL = Provisia long-grain; LH = long-grain hybrid; FLH = FullPage long-grain hybrid; LA = long-grain aromatic.

[b] Relative straw strength based on field tests using the scale: 1 = very strong straw, 5=very weak straw; based on percent lodging.

[c] Number of days from plant emergence until 50% of the panicles are visibly emerging from the boot.

[d] %HR/%TR = % head rice/%total rice.

Utilization of On-Farm Testing to Evaluate Rice Cultivars, 2020

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Abstract

On-farm cultivar testing provides the ability to evaluate performance in commercial fields with more unpredictable environments than those at traditional research stations. The Commercial Rice Trials (CRT) utilize commercial fields and experiment stations throughout the state of Arkansas to evaluate different rice cultivars, including experimental and commercial lines. These on-farm tests are used to analyze different agronomic aspects of cultivars such as disease, lodging, plant stand, plant height, grain yield, and milling yield in diverse environmental conditions, soil types, and growing practices. The most important decision for a producer can be the cultivar that will provide the maximum yield potential for each field. On-farm testing can indicate the cultivars that are best suited for a particular growing situation. Studies in 2020 were located in grower fields in Clay, Desha, Greene, Jackson, Jefferson, Lawrence, Lonoke, Phillips, and Poinsett counties. Three studies were located on research stations, including the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas in Arkansas Co.; the Pine Tree Research Station (PTRS) near Colt, Arkansas in St. Francis Co.; and the Northeast Research and Extension Center (NEREC) near Keiser, Arkansas in Mississippi Co. The average grain yield across all 12 locations was 206 bu./ac, and the location with the highest grain yield average was Jackson County at 234 bu./ac. The cultivars with the highest average grain yield across all locations were RT XP753, RT 7501, RT 7401, RT 7301, RT 7801, RT 7321 FP, RT 7521 FP, DG263L, and DGL044. Cultivars with the highest average milling yields were Lynx, Jupiter, Titan, ARX7-1127, CLM04, and DGL2065.

Introduction

One goal of the University of Arkansas System Division of Agriculture is to offer a complete production package to producers when southern U.S. rice cultivars are released, including grain and milling yield potential, disease reactions, fertilizer recommendations, and Degree-Day 50 (DD50) Rice Management Program thresholds. Factors that can influence grain yield potential include seeding date, soil fertility, water quality and management, disease pressure, weather events, and cultural management practices.

Rice disease can be a major factor in the profitability of any rice field in Arkansas. Host-plant resistance, optimum farming practices, and fungicide (when necessary, based on integrated pest management practices) are the best line of defense we have against these profit-robbing diseases. The use of resistant cultivars, combined with optimum cultural practices, provides growers with the opportunity to maximize profit at the lowest disease control expense by avoiding the use of costly fungicide applications.

New rice cultivars are developed and evaluated each year at the University of Arkansas System Division of Agriculture under controlled experiment station conditions. A large set of data on grain yield, grain quality, plant growth habit, and major disease resistance is collected during this process. Unfortunately, the dataset under these conditions is not complete for many of the environments where rice is grown in Arkansas because potential problems may not be evident in nurseries grown on experiment stations. With the information obtained from field research coupled with knowledge of a particular field history, growers can select the cultivar that offers the highest yield potential for their particular situation.

The Commercial Rice Trials (CRT) was designed to better address the many risks faced by newly released cultivars across the rice-growing regions of Arkansas. The on-farm evaluation of new and commercial cultivars provides better information on disease development, lodging, grain yield potential, and milling yield under different environmental conditions and crop management practices. These studies also provide a hands-on educational opportunity for county agents, consultants, and producers.

The objectives of the CRTs include: 1) to compare the yield potential of commercially available cultivars and advanced experimental lines under commercial production field productions; 2) to monitor disease pressure in the different regions of Arkansas; and 3) to evaluate the performance of rice cultivars under those conditions not commonly observed on experiment stations.

Procedures

Field studies were located in Arkansas, Clay, Desha, Greene, Jackson, Jefferson, Lawrence, Lonoke, Mississippi, Phillips, Poinsett, and St. Francis counties for the 2020 growing season. Twenty-seven cultivars were selected for evaluation in the on-farm tests. Conventional (non-herbicide-tolerant) entries evalu-

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ated during 2020 included Diamond, DG263L, Jewel, Jupiter, Lynx, ProGold1, ProGold2, Titan, RT XP753, RT 7301, RT 7501, RT 7401, and RT 7801. Clearfield or FullPage lines included CLM04, CLL15, CLL16, CLL17, RT7321 FP, and RT7521 FP. The MaxAce lines included RTv7231MA. Provisia lines included PVL02. Experimental lines included RU1702140, RU1701127, RU1801101, RU1801169, DGL044, and DGL2065.

Plots were 8 rows (7.5-in. spacing) wide and 16.5-ft in length arranged in a randomized complete block design with four replications. Pure-line cultivars (varieties) were seeded at a rate of 36 seeds/ft^2 and hybrids were seeded at 12 seeds/ft^2. Trials were seeded on 10 April (Arkansas), 9 April (Clay), 4 May (Desha), 10 April (Greene), 11 May (Jackson), 11 May (Jefferson), 7 May (Lawrence), 4 May (Lonoke), 21 May (Mississippi), 5 May (Phillips), 22 April (Poinsett), and 21 April (St. Francis; Table 1). Since these experiments contain Clearfield, conventional, FullPage, MaxAce, and Provisia entries, all plots were managed as conventional cultivars.

Cultural practices varied somewhat among the CRT locations but overall were grown under conditions for high yield. Trials conducted in commercial fields were managed by the grower with the rest of the field in regard to fertilization, irrigation, and weed and insect control, but in most cases did not receive a fungicide application. If a fungicide was applied, it was considered in the disease ratings. Plots were inspected periodically and rated for disease. Percent lodging notes were taken immediately prior to harvest. At maturity, the center 4 rows of each plot were harvested, the moisture content and weight of the grain were determined, and a subsample of harvested grain was removed for milling purposes. Grain yields were adjusted to 12% moisture and reported on a bushels per acre (bu./ac) basis. A bushel of rice weighs 45 lb. The dried rice was milled to obtain percent head rice (%HR, whole kernels) and percent total white rice (%TR) to provide a milling yield expressed as %HR/%TR. Data were analyzed using analysis of variance, PROC GLM, SAS v. 9.4 (SAS Institute, Inc., N.C.) with means separated using Fisher's least significant difference test ($P = 0.05$).

Results and Discussion

All cultivars were represented at all locations during the 2020 growing season. A summary of the results by county and date of seeding is presented in Table 2. Across counties, the grain yield averaged 206 bu./ac. Cultivars RT XP753 and RT 7501 were the highest yielding, followed by RT 7301, RT 7401, RT 7801, DG263L, and RT 7321 FP. Cultivars with the highest milling yields included Lynx, Jupiter, Titan, ARX7-1127, CLM04, and DGL2065.

In the Arkansas Co. trial, the grain yield averaged 191 bu./ac across all cultivars (Table 3). The highest yielding entries were RTv7231 MA, RT 7301, RT XP753, RT 7321 FP, and CLX8-1101. The entries with the highest milling yield included Lynx, Titan, CLM04, and DGL044. The Arkansas Co. trial had the highest average milling yield for the 12 trial locations at 67/71 (%HR/%TR).

The Clay Co. location tied for the second-highest average grain yield of 224 bu./ac (Table 4). The highest yielding entries were DG263L, RT XP753, DGL044, RT 7301, RT 7401, Titan, and Lynx. There was notable lodging at this location for RT 7521 FP and RT 7501. The cultivars Lynx, Jupiter, CLM04, ARX7-1127, DGL2065, and Titan had the highest average milling yields.

In the Desha Co. trial, RT XP753, RT 7401, RT 7501, RT 7801, RT 7521 FP, RT 7321 FP, Diamond, and DG263L were the highest yielding cultivars (Table 5). Notable lodging at this location included cultivars Lynx, CLM04, CLL16, CLL17, PVL02, and DGL044. The entries with the highest average milling yields were Lynx, Jupiter, Titan, ARX7-1127, CLM04, and DGL2065.

At the Greene Co. trial, the average grain yield was 148 bu./ac (Table 6). Greene Co. was the lowest average yielding trial in 2020. PVL02 was the only cultivar with notable lodging. Cultivars with the highest average grain yield included DG263L, DGL044, CLL16, and RT 7501. Greene Co. also had the lowest average milling yield of 58/71 (%HR/%TR). Standing water for an extended period after planting drastically reduced plant stands at this location. In addition, rice stalk borer infestations were severe across the trial.

In the Jackson Co. trial, the grain yield for all cultivars averaged 234 bu./ac (Table 7). Jackson Co. was the highest yielding trial in 2020. The highest yielding cultivars were RT 7501, RT 7401, RT 7801, RT 7521 FP, and RT XP753. There was no noticeable lodging at this location. The average milling yield at Jackson Co. was 66/71 (%HR/%TR), which was the second-highest average across all 12 locations.

In the Jefferson Co. trial, the average grain yield was 218 bu./ac (Table 8). Cultivars with the highest grain yield included RT XP753, RT 7501, and RT 7521 FP. The cultivars with the highest milling yield average were Lynx, Jupiter, Titan, ARX7-1127, CLM04, and DGL2065.

Cultivars RT 7501, RT 7301, RT XP753, RT 7321 FP, DG263L, and RT 7401 had the highest average grain yields at the Lawrence Co. trial (Table 9). There was notable lodging that occurred with cultivars CLL17 and PVL02. The highest average milling yields for this location included cultivars Jewel, ProGold1, and RT 7801.

At the Lonoke Co. trial, the average grain yield was 201 bu./ac (Table 10). Notable lodging occurred for Lynx, CLL17, PVL02, RTv7231 MA, RT 7321 FP, RT 7521 FP, RT 7401, and RT 7801. Lonoke Co. had the second-lowest average milling yield of 59/70 (%HR/%TR). Cultivars with the highest milling yield average were Lynx, Jupiter, ARX7-1127, CLM04, and DGL2065.

Cultivars RT XP753, DG263L, RT 7501, RT 7801, RT 7401, RT, 7301, RT 7321 FP, and Lynx were the highest yielding at the Mississippi Co. location (Table 11). There was notable lodging at this location for RT 7521 FP. The entries with the highest average milling yields were Lynx, Titan, ARX7-1127, CLM04, Jupiter, and ProGold1. The average milling yield for Mississippi Co. was 63/71 (%HR/%TR).

Cultivars RT 7501, RT XP753, RT 7301, and RT 7801 were the highest grain yielding in the Phillips Co. trial (Table 12). There was notable lodging that occurred with Lynx, Jupiter, ARX7-1127, CLM04, DG263L, and DGL044. The average milling yield at Phillips Co. was 61/68 (%HR/%TR).

At the Poinsett Co. trial, the grain yield for all cultivars averaged 216 bu./ac (Table 13). Cultivars RT 7501, RT 7401, DG263L, RT XP753, and RT 7321 FP had the highest average grain yields. The average milling yield for this location was 64/72 (%HR/%TR). The cultivars with the highest average milling yield were Lynx, Titan, CLM04, PVL02, Jupiter, and ARX7-1127. There was notable lodging at this location for cultivars CLL17 and RTv7231 MA.

In the St. Francis Co. trial, the grain yield for all cultivars averaged 194 bu./ac (Table 14). Cultivars RT 7521 FP, RT 7401, RT XP753, RT 7501, RT 7321 FP, RT 7301, and DG263L had the highest average grain yields. The cultivars with the highest average milling yields for this location were Lynx, Jupiter, ARX7-1121, and CLM04.

Practical Applications

The 2020 Commercial Rice Trials provided additional data to the rice breeding and disease resistance programs. The program also provided supplemental performance and disease reaction data on new cultivars that will be more widely grown in Arkansas during 2021.

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Table 1. Field and agronomic information for Commercial Rice Trial (CRT) locations in 2020.

County	City	Soil Class	Land Type	Cultivar	Planting Date	Emergence Date	Harvest Date	Preflood N	Midseason N	Boot N
Arkansas	Stuttgart	Dewitt silt loam	Straight levee	n/a	4/10	4/27	8/24	130	0	0
St. Francis	Colt	Calhoun-Henry silt loam	Straight levee	n/a	4/21	5/6	9/9	145	0	0
Mississippi	Keiser	Sharkey silty clay	Straight levee	n/a	5/21	5/29	9/29	160	0	0
Clay	McDougal	Crowley silt loam	Straight levee	RT 7301	4/9	5/3	9/21	115	62	30
Desha	McGehee	Perry clay	Zero	RT 7801	5/4	5/11	9/17	145	0	35
Poinsett	Waldenburg	Henry-Hillemann silt loam	Contour levee	RT XP753	4/22	5/1	9/21	120	0	30
Lawrence	Walnut Ridge	Dubbs silt loam	Straight levee	Diamond	5/7	5/18	10/7	103	46	0
Jackson	Newport	Amagon & Forestdale silt loams	Straight levee	RT XP753	5/11	5/22	10/1	126	0	35
Jefferson	Altheimer	McGehee silt loam/Perry clay	Straight levee	Diamond	5/11	5/22	9/16	117	72	0
Greene	Paragould	Jackport silty clay loam	Zero	RT 7301	4/10	4/29	9/15	125	0	32
Phillips	Lambrook	Arkabutla silty clay loam	Straight levee	Diamond	5/5	5/19	10/5	125	46	0
Lonoke	England	Portland silty clay	Zero	RT XP753	5/4	5/10	9/8	135	0	0

Table 2. Results of the Commercial Rice Trials (CRT) at 12 locations during 2020.

Cultivar	Grain Length[a]	Lodging[b]	Milling Yield[c]	Grain Yield by Location and Planting Date												
				ARK[d]	STF	MIS	CLA	DES	POI	LAW	JAC	JEF	GRE	PHI	LON	MEAN
		%	%HR/%TR	bu./ac												
Diamond	L	0	60/70	182	171	221	226	227	188	216	219	235	145	208	199	203
Jewel	L	0	63/71	153	159	206	216	194	197	199	217	200	149	208	176	190
ProGold1	L	0	62/71	162	179	222	224	213	188	214	238	213	129	201	202	199
ProGold2	L	0	59/70	172	164	205	228	220	201	206	219	207	144	210	196	198
Lynx	M	14	65/71	192	200	227	232	165	225	220	246	219	157	132	220	187
Jupiter	M	4	66/70	165	177	212	215	196	218	216	230	198	160	171	194	196
Titan	M	0	65/71	182	195	205	233	190	217	225	212	198	159	209	189	201
ARX7-1127	M	4	66/70	161	172	219	207	188	213	224	240	197	163	179	168	194
CLM04	M	10	66/71	179	188	217	207	154	216	212	243	193	156	147	211	194
CLL15	L	0	62/69	210	187	196	218	189	198	225	206	207	152	173	200	197
CLL16	L	3	60/70	182	187	214	223	193	215	223	238	223	174	200	202	206
CLL17	L	7	62/69	193	184	210	220	168	192	186	198	182	137	160	166	183
CLX8-1101	L	0	63/70	217	198	201	226	193	203	195	212	201	139	202	201	199
CLX8-1169	L	0	63/70	183	188	201	221	203	209	193	210	196	133	177	207	193
PVL02	L	28	64/71	179	154	184	188	97	149	147	186	162	120	142	120	152
RTv7231 MA	L	13	59/70	225	213	217	211	218	206	225	201	228	145	201	185	206
RT 7321 FP	L	8	58/71	216	219	240	228	237	256	260	249	247	137	212	186	224
RT 7521 FP	L	21	61/71	202	225	222	175	238	248	237	262	258	136	202	213	218
RT 7301	L	5	59/72	205	216	240	246	247	237	269	243	234	152	226	228	229
RT 7401	L	9	61/71	221	232	242	245	251	260	255	288	240	157	213	226	236
RT 7501	L	7	62/72	210	222	246	227	248	264	276	295	258	164	233	230	239
RT 7801	L	8	61/71	193	197	243	227	248	244	239	287	240	153	217	219	226
RT XP753	L	1	61/72	218	224	261	252	251	251	267	261	252	128	237	239	237
DG263L	L	12	61/70	215	215	251	261	223	255	258	234	241	184	168	239	229

Continued

Table 2. Continued.

Cultivar	Grain Length[a]	Lodging[b]	Milling Yield[c]	Grain Yield by Location and Planting Date ARK[d]	STF	MIS	CLA	DES	POI	LAW	JAC	JEF	GRE	PHI	LON	MEAN
		%	%HR/%TR	bu./ac												
DGL044	L	10	63/70	172	183	224	244	200	214	232	234	219	179	190	219	209
DGL2065	L	0	65/71	180	184	198	214	201	159	210	216	215	82	201	196	188
MEAN	--	6	62/70	191	194	220	224	206	216	224	234	218	148	193	201	206
$LSD_{0.05}$[e]	--	5.1	1.0/0.6	12.5	17.7	16.3	25.5	29.9	17.4	19.2	26.3	30.1	27.6	29.8	24.0	7.0

[a] Grain length: L = long-grain; M = medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Milling yield = % Head Rice/% Total Rice.

[d] ARK = Arkansas Co., Rice Research & Extension Center, Stuttgart, Ark.; STF = St. Francis Co., Pine Tree Research Station, Colt, Ark.; MIS = Mississippi Co., Northeast Research & Extension Center, Keiser, Ark.; CLA = Clay Co., producer field near McDougal, Ark.; DES = Desha Co., producer field near McGehee, Ark.; POI = Poinsett Co., producer field near Waldenburg, Ark.; LAW = Lawrence Co., producer field near O'Kean, Ark.; JAC = Jackson Co., producer field near Newport, Ark.; JEF = Jefferson Co., producer field near Altheimer, Ark.; GRE = Greene Co.; producer field near Paragould, Ark.; PHI = Phillips Co., producer field near Lambrook, Ark.; LON = Lonoke Co., producer field near England, Ark.

[e] LSD = least significant difference.

Table 3. Results of Arkansas Co. Commercial Rice Trial (CRT) during 2020 (planted 10 April; harvested 24 August).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	18.7	182	64/71
Jewel	L	0	17.8	153	63/70
ProGold1	L	0	18.6	162	68/73
ProGold2	L	0	17.2	172	61/69
Lynx	M	0	19.2	192	69/72
Jupiter	M	0	20.2	165	68/70
Titan	M	0	17.0	182	68/72
ARX7-1127	M	0	20.4	161	67/70
CLM04	M	0	18.3	179	69/71
CLL15	L	0	17.2	210	65/71
CLL16	L	0	20.2	182	63/70
CLL17	L	0	16.2	193	64/69
CLX8-1101	L	0	18.3	217	66/71
CLX8-1169	L	0	19.0	183	65/71
PVL02	L	0	13.9	179	65/71
RTv7231 MA	L	0	14.9	225	64/72
RT 7321 FP	L	0	14.4	216	61/72
RT 7521 FP	L	0	16.4	202	64/72
RT 7301	L	0	15.4	205	64/72
RT 7401	L	0	15.5	221	65/73
RT 7501	L	0	16.5	210	66/73
RT 7801	L	0	18.6	193	64/71
RT XP753	L	0	14.5	218	64/73
DG263L	L	0	17.5	215	65/70
DGL044	L	0	20.4	172	68/70
DGL2065	L	0	17.3	180	60/73
MEAN	-	0	17.4	191	67/71
$LSD_{0.05}$[e]	-	0	1.2	12.5	2.3/1.9

[a] Grain length: L = long-grain; M = medium-grain.
[b] Lodging = % of plot down at harvest.
[c] Grain moisture at harvest.
[d] Milling yield = % Head Rice/% Total Rice.
[e] LSD = least significant difference.

Table 4. Results of Clay Co. Commercial Rice Trial (CRT) during 2020 (planted 9 April; harvested 21 September).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	10.7	226	58/70
Jewel	L	0	10.6	216	61/70
ProGold1	L	0	10.7	224	59/72
ProGold2	L	0	10.6	228	57/70
Lynx	M	0	11.4	232	67/73
Jupiter	M	0	12.9	215	67/71
Titan	M	0	10.7	233	64/73
ARX7-1127	M	0	18.9	207	67/71
CLM04	M	0	13.7	207	67/71
CLL15	L	0	10.5	218	61/70
CLL16	L	0	11.5	223	56/69
CLL17	L	0	10.5	220	62/70
CLX8-1101	L	0	9.8	226	63/71
CLX8-1169	L	0	10.2	221	62/71
PVL02	L	0	10.3	188	63/72
RTv7231 MA	L	0	9.8	211	54/69
RT 7321 FP	L	0	10.0	228	55/71
RT 7521 FP	L	100	10.4	175	57/71
RT 7301	L	0	9.9	246	54/71
RT 7401	L	0	10.1	245	58/71
RT 7501	L	26.7	10.6	227	61/74
RT 7801	L	0	10.6	227	55/71
RT XP753	L	0	10.2	252	58/73
DG263L	L	0	9.1	261	59/71
DGL044	L	0	12.0	244	60/69
DGL2065	L	0	10.1	214	64/72
MEAN	-	4.9	11.0	224	60/71
$LSD_{0.05}$[e]	-	10.4	1.4	25.5	2.6/2.0

[a] Grain length: L = long-grain; M = medium-grain.
[b] Lodging = % of plot down at harvest.
[c] Grain moisture at harvest.
[d] Milling yield = % Head Rice/% Total Rice.
[e] LSD = least significant difference.

Table 5. Results of Desha Co. Commercial Rice Trial (CRT) during 2020 (planted 4 May; harvested 17 September).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	12.3	227	60/70
Jewel	L	0	11.9	194	61/71
ProGold1	L	0	11.9	213	62/71
ProGold2	L	0	11.9	220	63/72
Lynx	M	25	12.8	165	66/71
Jupiter	M	0	14.0	196	67/71
Titan	M	0	12.3	190	67/71
ARX7-1127	M	0	13.5	188	68/71
CLM04	M	20	12.8	154	68/71
CLL15	L	0	11.6	189	61/68
CLL16	L	20	12.5	193	58/70
CLL17	L	10	11.7	168	62/69
CLX8-1101	L	0	11.7	193	63/67
CLX8-1169	L	0	12.1	203	62/70
PVL02	L	100	12.9	97	65/72
RTv7231 MA	L	0	11.3	218	61/70
RT 7321 FP	L	0	10.8	237	61/72
RT 7521 FP	L	0	11.9	238	63/72
RT 7301	L	0	10.8	247	64/73
RT 7401	L	0	12.9	251	64/72
RT 7501	L	0	11.2	248	65/73
RT 7801	L	0	12.1	248	64/72
RT XP753	L	0	11.1	251	65/74
DG263L	L	0	11.8	223	63/71
DGL044	L	10	12.7	200	64/71
DGL2065	L	0	12.0	201	66/71
MEAN	-	7.1	12.1	206	63/71
$LSD_{0.05}$[e]	-	21.6	0.9	29.9	1.7/1.5

[a] Grain length: L = long-grain; M = medium-grain.
[b] Lodging = % of plot down at harvest.
[c] Grain moisture at harvest.
[d] Milling yield = % Head Rice/% Total Rice.
[e] LSD = least significant difference.

Table 6. Results of Greene Co. Commercial Rice Trial (CRT) during 2020 (planted 10 April; harvested 15 September).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	11.9	145	59/71
Jewel	L	0	11.6	149	64/72
ProGold1	L	0	13.6	129	58/71
ProGold2	L	0	12.3	144	56/71
Lynx	M	0	11.4	157	53/70
Jupiter	M	0	12.6	160	63/70
Titan	M	0	11.4	159	49/70
ARX7-1127	M	0	12.5	163	63/70
CLM04	M	0	12.1	156	60/71
CLL15	L	0	11.6	152	59/70
CLL16	L	0	12.4	174	57/70
CLL17	L	0	11.3	137	60/70
CLX8-1101	L	0	11.7	139	59/70
CLX8-1169	L	0	12.2	133	59/70
PVL02	L	50	10.9	120	56/70
RTv7231 MA	L	0	10.9	145	50/69
RT 7321 FP	L	0	10.6	137	49/71
RT 7521 FP	L	0	10.9	136	60/73
RT 7301	L	0	11.0	152	50/71
RT 7401	L	0	10.8	157	54/70
RT 7501	L	0	10.7	164	58/71
RT 7801	L	0	11.2	153	56/69
RT XP753	L	0	11.3	128	56/71
DG263L	L	0	10.6	184	62/69
DGL044	L	0	13.5	179	64/71
DGL2065	L	0	11.8	82	65/72
MEAN	-	1.9	11.6	148	58/71
$LSD_{0.05}$[e]	-	15.8	1.1	27.6	7.0/1.4

[a] Grain length: L = long-grain; M = medium-grain.
[b] Lodging = % of plot down at harvest.
[c] Grain moisture at harvest.
[d] Milling yield = % Head Rice/% Total Rice.
[e] LSD = least significant difference.

Table 7. Results of Jackson Co. Commercial Rice Trial (CRT) during 2020 (planted 11 May; harvested 1 October).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	12.4	219	66/72
Jewel	L	0	12.3	217	67/72
ProGold1	L	0	11.8	238	65/72
ProGold2	L	0	12.6	219	64/72
Lynx	M	0	13.1	246	68/72
Jupiter	M	0	13.9	230	67/70
Titan	M	0	11.9	212	68/72
ARX7-1127	M	0	13.4	240	68/70
CLM04	M	0	13.0	243	68/71
CLL15	L	0	11.8	206	66/71
CLL16	L	0	13.9	238	63/71
CLL17	L	0	11.7	198	65/70
CLX8-1101	L	0	11.9	212	67/71
CLX8-1169	L	0	12.7	210	67/72
PVL02	L	0	11.0	186	68/72
RTv7231 MA	L	0	11.2	201	65/71
RT 7321 FP	L	0	10.4	249	61/72
RT 7521 FP	L	0	11.6	262	65/72
RT 7301	L	0	10.9	243	63/72
RT 7401	L	0	11.4	288	64/72
RT 7501	L	0	12.0	295	66/72
RT 7801	L	0	13.8	287	64/71
RT XP753	L	0	10.8	261	64/73
DG263L	L	0	12.4	234	64/69
DGL044	L	0	16.3	234	64/71
DGL2065	L	0	12.0	216	67/72
MEAN	-	0	12.3	234	66/71
$LSD_{0.05}$[e]	-	0	0.9	26.3	1.6/0.7

[a] Grain length: L = long-grain; M = medium-grain.
[b] Lodging = % of plot down at harvest.
[c] Grain moisture at harvest.
[d] Milling yield = % Head Rice/% Total Rice.
[e] LSD = least significant difference.

Table 8. Results of Jefferson Co. Commercial Rice Trial (CRT) during 2020 (planted 11 May; harvested 16 September).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	13.5	235	62/71
Jewel	L	0	12.9	200	65/72
ProGold1	L	0	13.4	213	65/72
ProGold2	L	0	12.4	207	63/73
Lynx	M	0	13.6	219	67/71
Jupiter	M	0	17.1	198	68/70
Titan	M	0	12.9	198	67/71
ARX7-1127	M	0	16.8	197	68/70
CLM04	M	0	15.2	193	68/71
CLL15	L	0	12.7	207	64/71
CLL16	L	0	14.6	223	63/70
CLL17	L	0	13.0	182	64/69
CLX8-1101	L	0	13.3	201	65/71
CLX8-1169	L	0	13.4	196	65/71
PVL02	L	30	12.0	162	66/71
RTv7231 MA	L	45	12.3	228	62/70
RT 7321 FP	L	0	11.5	247	61/71
RT 7521 FP	L	0	13.1	258	62/71
RT 7301	L	0	12.1	234	61/72
RT 7401	L	0	12.6	240	63/71
RT 7501	L	0	13.1	258	64/72
RT 7801	L	0	14.7	240	63/71
RT XP753	L	6.7	11.6	252	61/72
DG263L	L	0	12.5	241	64/69
DGL044	L	0	17.2	219	66/72
DGL2065	L	0	13.0	215	67/72
MEAN	-	3.1	13.5	218	64/71
$LSD_{0.05}$[e]	-	17.4	1.1	30.1	2.4/1.0

[a] Grain length: L = long-grain; M = medium-grain.
[b] Lodging = % of plot down at harvest.
[c] Grain moisture at harvest.
[d] Milling yield = % Head Rice/% Total Rice.
[e] LSD = least significant difference.

Table 9. Results of Lawrence Co. Commercial Rice Trial (CRT) during 2020 (planted 7 May; harvested 7 October).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	16.6	215	59/67
Jewel	L	0	17.7	199	65/71
ProGold1	L	0	16.7	214	64/70
ProGold2	L	0	16.9	206	61/70
Lynx	M	0	15.4	220	61/67
Jupiter	M	0	19.4	216	64/68
Titan	M	0	14.6	225	65/69
ARX7-1127	M	0	18.7	224	64/68
CLM04	M	0	16.7	212	64/69
CLL15	L	0	16.2	225	62/68
CLL16	L	0	19.3	223	63/70
CLL17	L	10	15.9	186	60/66
CLX8-1101	L	0	16.9	195	63/69
CLX8-1169	L	0	16.7	193	61/68
PVL02	L	55	15.5	147	63/70
RTv7231 MA	L	0	14.7	225	60/69
RT 7321 FP	L	0	14.5	261	61/71
RT 7521 FP	L	0	15.3	237	59/68
RT 7301	L	0	14.5	269	61/70
RT 7401	L	0	16.1	255	61/69
RT 7501	L	0	16.5	276	63/71
RT 7801	L	0	20.0	239	64/70
RT XP753	L	0	14.2	267	63/71
DG263L	L	0	15.0	258	59/67
DGL044	L	0	19.0	232	61/68
DGL2065	L	0	15.5	210	63/69
MEAN	-	2.5	16.5	224	62/69
$LSD_{0.05}$[e]	-	15.3	2.0	19.2	2.2/1.3

[a] Grain length: L = long-grain; M = medium-grain.
[b] Lodging = % of plot down at harvest.
[c] Grain moisture at harvest.
[d] Milling yield = % Head Rice/% Total Rice.
[e] LSD = least significant difference.

Table 10. Results of Lonoke Co. Commercial Rice Trial (CRT) during 2020 (planted 6 May; harvested 8 September).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	15.4	199	56/70
Jewel	L	0	15.3	176	57/71
ProGold1	L	0	14.9	202	57/71
ProGold2	L	0	14.4	196	49/70
Lynx	M	42.5	15.7	220	65/70
Jupiter	M	0	20.1	194	66/69
Titan	M	0	15.5	189	62/70
ARX7-1127	M	0	20.4	168	65/69
CLM04	M	0	16.9	211	66/70
CLL15	L	0	14.7	200	59/70
CLL16	L	0	16.6	202	54/69
CLL17	L	62.5	16.6	166	62/70
CLX8-1101	L	0	14.7	201	60/70
CLX8-1169	L	0	14.6	207	60/70
PVL02	L	90.0	14.8	120	63/72
RTv7231 MA	L	99.5	14.6	185	47/67
RT 7321 FP	L	94.5	15.6	186	49/69
RT 7521 FP	L	72.5	14.1	213	58/70
RT 7301	L	40.0	15.1	228	53/70
RT 7401	L	87.5	14.0	226	57/70
RT 7501	L	31.25	14.2	230	56/70
RT 7801	L	67.5	16.1	219	56/69
RT XP753	L	7.5	13.3	239	53/70
DG263L	L	52.0	15.4	239	59/69
DGL044	L	57.5	18.8	219	63/71
DGL2065	L	0	14.8	196	64/72
MEAN	-	31.0	15.6	201	59/70
$LSD_{0.05}$[e]	-	26.7	1.6	24.0	2.9/0.8

[a] Grain length: L = long-grain; M = medium-grain.
[b] Lodging = % of plot down at harvest.
[c] Grain moisture at harvest.
[d] Milling yield = % Head Rice/% Total Rice.
[e] LSD = least significant difference.

Table 11. Results of Mississippi Co. Commercial Rice Trial (CRT) during 2020 (planted 21 May; harvested 29 September).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	16.1	221	63/71
Jewel	L	0	16.5	206	62/69
ProGold1	L	0	15.5	222	65/74
ProGold2	L	0	15.2	205	58/65
Lynx	M	0	15.3	227	68/73
Jupiter	M	0	20.2	212	67/71
Titan	M	0	14.1	205	68/72
ARX7-1127	M	0	17.9	219	68/71
CLM04	M	0	17.2	217	67/71
CLL15	L	0	14.9	196	63/70
CLL16	L	0	16.7	214	60/69
CLL17	L	0	14.0	210	60/68
CLX8-1101	L	0	14.5	201	65/71
CLX8-1169	L	0	15.7	201	64/71
PVL02	L	0	13.5	184	63/70
RTv7231 MA	L	0	12.8	217	61/72
RT 7321 FP	L	0	1.5	240	60/72
RT 7521 FP	L	57.5	13.2	222	59/70
RT 7301	L	0	12.9	240	60/71
RT 7401	L	0	12.3	242	58/70
RT 7501	L	0	14.1	246	63/73
RT 7801	L	0	16.9	243	62/72
RT XP753	L	0	12.8	261	60/71
DG263L	L	0	13.4	251	60/72
DGL044	L	0	17.5	224	62/69
DGL2065	L	0	14.3	198	63/70
MEAN	-	2	14.6	220	63/71
$LSD_{0.05}$[e]	-	10.9	2.0	16.3	3.7/3.9

[a] Grain length: L = long-grain; M = medium-grain.
[b] Lodging = % of plot down at harvest.
[c] Grain moisture at harvest.
[d] Milling yield = % Head Rice/% Total Rice.
[e] LSD = least significant difference.

Table 12. Results of Phillips Co. Commercial Rice Trial (CRT) during 2020 (planted 5 May; harvested 5 October).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	15.5	208	59/67
Jewel	L	0	15.8	208	63/69
ProGold1	L	0	17.1	201	62/69
ProGold2	L	0	15.2	210	61/69
Lynx	M	100	15.9	132	56/67
Jupiter	M	47.5	18.1	171	65/69
Titan	M	0	14.5	209	63/69
ARX7-1127	M	42.5	17.4	179	63/69
CLM04	M	95	17.0	147	61/68
CLL15	L	0	14.6	173	58/65
CLL16	L	12.5	17.0	200	57/66
CLL17	L	0	14.5	160	57/63
CLX8-1101	L	0	14.1	202	61/68
CLX8-1169	L	0	16.5	177	63/69
PVL02	L	0	14.4	142	61/68
RTv7231 MA	L	0	13.2	201	58/68
RT 7321 FP	L	0	13.7	212	60/71
RT 7521 FP	L	25	15.3	202	60/69
RT 7301	L	0	14.5	226	61/71
RT 7401	L	20	14.1	213	61/69
RT 7501	L	25	14.6	233	62/69
RT 7801	L	25	15.6	217	61/69
RT XP753	L	0	13.6	237	63/71
DG263L	L	93.3	17.4	168	55/67
DGL044	L	50	18.5	190	61/68
DGL2065	L	0	15.0	201	63/70
MEAN	-	20.6	15.5	193	61/68
$LSD_{0.05}$[e]	-	38.6	1.9	29.8	2.6/1.6

[a] Grain length: L = long-grain; M = medium-grain.
[b] Lodging = % of plot down at harvest.
[c] Grain moisture at harvest.
[d] Milling yield = % Head Rice/% Total Rice.
[e] LSD = least significant difference.

Table 13. Results of Poinsett Co. Commercial Rice Trial (CRT) during 2020. (planted 22 April; harvested 21 September).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	20.3	188	63/71
Jewel	L	0	20.2	197	65/72
ProGold1	L	0	20.5	188	64/71
ProGold2	L	0	18.8	201	64/72
Lynx	M	0	18.7	225	67/71
Jupiter	M	0	20.6	218	66/70
Titan	M	0	17.5	217	68/72
ARX7-1127	M	0	21.0	213	67/70
CLM04	M	0	19.6	216	68/71
CLL15	L	0	16.5	198	65/72
CLL16	L	0	20.6	215	61/71
CLL17	L	3.8	16.6	192	64/71
CLX8-1101	L	0	16.3	203	65/72
CLX8-1169	L	0	19.1	209	64/72
PVL02	L	5	15.0	149	66/73
RTv7231 MA	L	10	15.2	206	63/72
RT 7321 FP	L	0	14.7	256	62/73
RT 7521 FP	L	0	15.9	248	63/72
RT 7301	L	0	15.6	237	63/73
RT 7401	L	0	16.9	260	64/73
RT 7501	L	0	18.1	264	65/73
RT 7801	L	0	20.2	244	62/71
RT XP753	L	0	16.0	251	63/73
DG263L	L	0	16.8	255	63/71
DGL044	L	0	22.9	214	63/71
DGL2065	L	0	20.2	159	65/72
MEAN	-	0.7	18.2	216	64/72
$LSD_{0.05}$[e]	-	6.1	2.0	17.4	1.5/1.0

[a] Grain length: L = long-grain; M = medium-grain.
[b] Lodging = % of plot down at harvest.
[c] Grain moisture at harvest.
[d] Milling yield = % Head Rice/% Total Rice.
[e] LSD = least significant difference.

Table 14. Results of St. Francis Co. Commercial Rice Trial (CRT) during 2020 (planted 21 April; harvested 9 September).

Cultivar	Grain Length[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	0	17.2	171	60/71
Jewel	L	0	17.4	159	62/71
ProGold1	L	0	17.7	179	60/72
ProGold2	L	0	17.0	164	55/69
Lynx	M	0	14.9	200	69/76
Jupiter	M	0	18.7	177	68/72
Titan	M	0	15.7	195	65/72
ARX7-1127	M	0	17.8	172	67/71
CLM04	M	0	15.6	188	69/73
CLL15	L	0	14.8	187	62/69
CLL16	L	0	17.6	187	62/72
CLL17	L	0	13.4	184	63/70
CLX8-1101	L	0	15.0	198	63/71
CLX8-1169	L	0	15.8	188	63/70
PVL02	L	0	13.9	154	65/71
RTv7231 MA	L	0	14.0	213	61/73
RT 7321 FP	L	0	12.9	219	58/71
RT 7521 FP	L	0	13.2	225	62/71
RT 7301	L	0	13.6	216	56/73
RT 7401	L	0	14.8	232	63/73
RT 7501	L	0	14.9	222	63/72
RT 7801	L	0	17.1	197	61/72
RT XP753	L	0	13.1	224	59/72
DG263L	L	0	14.8	215	62/71
DGL044	L	0	18.0	183	63/70
DGL2065	L	0	14.2	184	65/71
MEAN	-	0	15.5	194	65/72
$LSD_{0.05}$[e]	-	0	1.5	17.7	2.9/2.9

[a] Grain length: L = long-grain; M = medium-grain.
[b] Lodging = % of plot down at harvest.
[c] Grain moisture at harvest.
[d] Milling yield = % Head Rice/% Total Rice.
[e] LSD = least significant difference.

2020 Rice Grower Research and Demonstration Experiment Program

K.F. Hale[1] *and J.T. Hardke*[1]

Abstract

In 2020, the Rice Grower Research and Demonstration Experiment (GRADE) Program was conducted in commercial rice fields at six locations across Arkansas. Trials consisted of replicated, large-block demonstrations evaluating rice varieties. The University of Arkansas System Division of Agriculture and the Arkansas Rice Research and Promotion Board first initiated this program in 2017 to conduct large block replicated field trials on grower farms to bridge information between small plot research trials and grower field experiences. It is a collaborative effort between growers, consultants, county Extension agents, Extension specialists, and researchers using large block plots of approximately one-half acre or larger within a grower's field to achieve our goals.

Introduction

The Rice Grower Research and Demonstration Experiment (GRADE) Program has continued to grow and develop since it began in the 2017 growing season when it was established by the University of Arkansas System Division of Agriculture's Cooperative Extension Service and the Arkansas Rice Research and Promotion Board. The purpose is to coordinate and demonstrate large-scale plots to indorse the performance of rice recommendations and cultivars in commercial production fields across the Arkansas production region. This program is meeting its overall objective by increasing confidence and visibility of research as well as bridging the gap between small-plot research trials and whole-field verification program demonstrations.

The goals of the Rice GRADE Program are 1) to execute large-scale trials on commercial rice farms; 2) to increase large-plot research data on cultivar performance; 3) to arrange hands-on training of agents, consultants, and growers; 4) to produce data to support the development of rice budgets, computer-assisted management programs, agronomic practices, resource utilization, and statewide rice extension programs.

Demonstrations of this type would allow more hands-on participation by county agents, consultants, and others while providing multiple sites for educational field events. Additional benefits would also include the ability to provide supplemental information to the verification program as well as allowing more growers opportunities to evaluate and provide input on practices at a larger scale than small-plot research in multiple counties across the state. Long term, the success of this program should result in the adoption of lower risk recommended practices and increase whole farm revenue.

Procedures

Prior to planting, six fields were selected for involvement in the Rice GRADE Program for the 2020 season. Variety demonstration trials in 2020 were located in Craighead, Jefferson, Lonoke, Lee, Monroe, and Drew Counties. A randomized complete block design with 4 replications was used in the implementation of all trials.

All variety demonstrations were planted, including the cultivars Diamond, CLL15, and Jewel. Variety demonstrations were seeded with a John Deere 6120E tractor used to pull an 8-ft Great Plains no-till box drill. Based on equipment size and field layout, each variety demonstration plot ranged in size from 24–40 ft wide and 500–600 ft in length.

Throughout the growing season, related data were collected during routine visits monitoring the growth and development of the crop by the program coordinator. In addition to the needed input from the program coordinator, county agent, and Rice Extension Agronomist, the overall management of the trial area is based on standard grower practices.

The demonstrations compared the varieties Diamond, CLL15, and Jewel planted at the standard recommended seeding rate. Harvest was completed with cooperator combine harvesters and weights collected with a weigh wagon. Grain yield was corrected to 12% moisture and reported in bushels per acre (bu./ac). Samples were collected to evaluate harvest moisture and test weight, then dried to 12% moisture to evaluate for milling yields as percent head rice (%HR) and total milled rice (%TR) reported as %HR/%TR. Data were analyzed using PROC GLM in SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) and means separated using Fisher's least significant difference test ($P = 0.10$).

Results and Discussion

In the Craighead County variety demonstration, there were no significant differences between the varieties for any factors evaluated (Table 1). However, Jewel produced both the highest average grain yield and highest milling yields of the varieties in the trial. These findings corresponded with the plant stand data, which showed Jewel to have a higher stand density than either CLL15 or Diamond.

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In the Drew County variety demonstration, there were no significant differences in grain yield among the three varieties evaluated (Table 2). However, CLL15 had the highest overall yield among the three varieties. Head rice yield for CLL15 was greater than that for Jewel, and total rice for CLL15 was greater than that for both Diamond and Jewel. Lower overall yields at this location could possibly be attributed to later planting date (1 June).

At the Jefferson County variety demonstration, Jewel produced significantly higher grain yields than CLL15 and Diamond (Table 3). While not significant, Diamond and Jewel produced higher percent head rice than CLL15. The Jefferson County location produced the highest overall grain yields of the six variety demonstrations.

In the Lee County variety demonstration, Jewel produced significantly higher grain yields than both CLL15 and Diamond (Table 4). Diamond also produced greater yields than CLL15. Jewel had a significantly higher stand density than both CLL15 and Diamond. There were no differences in milling yield among the three varieties.

In the Lonoke County variety demonstration, there were no significant differences for any factors evaluated (Table 5). However, CLL15 produced the highest overall grain yield. Additionally, results for %HR and %TR were similar among all three varieties.

In the Monroe County variety demonstration, Diamond produced yields significantly greater than CLL15 and Jewel (Table 6). In addition, Jewel had greater yields than CLL15. For %HR, Jewel and CLL15 had higher values than Diamond; but for %TR, Jewel was greater than both Diamond and CLL15.

A summary of results across all six demonstration sites can be found in Table 7. Overall, Jewel produced significantly higher yields than CLL15 but was similar to Diamond. Jewel also had an average plant stand significantly greater than Diamond. Head rice and total rice values were similar among all three varieties.

Practical Applications

Data collected from the 2020 Rice GRADE Program provides support for data produced from small-plot research. This information can be used to aid in variety selection.

Acknowledgments

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Table 1. Craighead County Variety Demonstration near Cash, Arkansas, in 2020.

Cultivar	Plant Stand	Harvest Moisture	Test Weight	Grain Yield	Head Rice	Total Rice
	(plant/ft^2)	(%)	(lb/bu.)	(bu./ac)	(%)	(%)
CLL15	16.3	17.8	45.8	164.6	53.9	65.9
Diamond	16.8	19.3	46.2	159.3	55.4	67.1
Jewel	20.8	19.1	46.1	170.6	57.8	67.8
P-value	0.1045	0.2186	0.6937	0.4539	0.3975	0.6523
CV†	15.0	6.13	1.28	7.21	6.72	4.23
$LSD_{0.10}$†	NS†	NS	NS	NS	NS	NS

† CV = coefficient of variation; LSD = least significant difference; NS = not significant.

Table 2. Drew County Variety Demonstration near McGehee, Arkansas, in 2020.

Cultivar	Plant Stand	Harvest Moisture	Test Weight	Grain Yield	Head Rice	Total Rice
	(plant/ft^2)	(%)	(lb/bu.)	(bu./ac)	(%)	(%)
CLL15	23.5 b†	18.7	43.8	147.0	59.4 a	67.0 a
Diamond	21.5 b	17.8	45.5	140.2	56.8 ab	65.9 b
Jewel	28.8 a	19.2	45.0	139.8	54.0 b	65.8 b
P-value	0.0026	0.2828	0.2076	0.4038	0.0473	0.0268
CV‡	7.01	6.43	2.78	5.57	4.12	0.75
$LSD_{0.10}$‡	2.4	NS‡	NS	NS	3.2	0.7

† Means within a column followed by the same letter are not significantly different ($P > 0.1$).
‡ CV = coefficient of variation; LSD = least significant difference; NS = not significant.

Table 3. Jefferson County Variety Demonstration near Altheimer, Arkansas, in 2020.

Cultivar	Plant Stand	Harvest Moisture	Test Weight	Grain Yield	Head Rice	Total Rice
	(plant/ft^2)	(%)	(lb/bu.)	(bu./ac)	(%)	(%)
CLL15	28.5	13.8	43.7	188.8 b†	55.4	68.3
Diamond	27.0	14.1	43.9	191.9 b	58.5	69.1
Jewel	25.3	13.9	42.1	213.4 a	58.0	69.5
P-value	0.4412	0.8064	0.6135	0.0071	0.2379	0.4211
CV‡	12.46	5.32	6.27	3.80	4.24	1.72
$LSD_{0.10}$‡	NS‡	NS	NS	10.3	NS	NS

† Means within a column followed by the same letter are not significantly different ($P > 0.1$).
‡ CV = coefficient of variation; LSD = least significant difference; NS = not significant.

Table 4. Lee County Variety Demonstration near Moro, Arkansas, in 2020.

Cultivar	Plant Stand	Harvest Moisture	Test Weight	Grain Yield	Head Rice	Total Rice
	(plant/ft^2)	(%)	(lb/bu.)	(bu./ac)	(%)	(%)
CLL15	18.8 b†	14.5	42.9	159.7 c	52.2	67.9
Diamond	16.8 b	14.6	42.5	172.1 b	53.3	68.3
Jewel	24.0 a	14.2	42.6	184.0 a	53.3	67.9
P-value	0.0656	0.7129	0.9094	0.0085	0.4747	0.7330
CV‡	17.92	4.27	3.36	4.12	2.61	1.11
$LSD_{0.10}$‡	4.9	NS‡	NS	9.7	NS	NS

† Means within a column followed by the same letter are not significantly different ($P > 0.1$).
‡ CV = coefficient of variation; LSD = least significant difference; NS = not significant.

Table 5. Lonoke County Variety Demonstration near Lonoke, Arkansas, in 2020.

Cultivar	Plant Stand	Harvest Moisture	Test Weight	Grain Yield	Head Rice	Total Rice
	(plant/ft^2)	(%)	(lb/bu.)	(bu./ac)	(%)	(%)
CLL15	26.3	13.5	43.1	192.5	54.5	68.6
Diamond	27.3	13.5	43.9	183.3	55.2	68.9
Jewel	22.8	13.5	42.8	180.2	54.6	68.5
P-value	0.5329	0.9981	0.3298	0.1374	0.8501	0.6980
CV†	22.22	4.91	2.41	4.10	3.49	0.97
$LSD_{0.10}$†	NS†	NS	NS	NS	NS	NS

† CV = coefficient of variation; LSD = least significant difference; NS = not significant.

Table 6. Monroe County Variety Demonstration near Blackton, Arkansas, in 2020.

Cultivar	Plant Stand	Harvest Moisture	Test Weight	Grain Yield	Head Rice	Total Rice
	(plant/ft^2)	(%)	(lb/bu.)	(bu./ac)	(%)	(%)
CLL15	23.8	17.0	39.8	152.0 c†	54.8 a	65.7 b
Diamond	24.0	17.3	40.3	180.3 a	51.1 b	65.8 b
Jewel	25.8	17.4	41.2	167.1 b	55.8 a	67.7 a
P-value	0.2989	0.5743	0.3092	<0.0001	0.0002	0.0017
CV‡	7.30	3.51	2.99	1.35	1.33	0.72
$LSD_{0.10}$‡	NS‡	NS	NS	3.1	1.0	0.7

† Means within a column followed by the same letter are not significantly different ($P > 0.1$).

‡ CV = coefficient of variation; LSD = least significant difference; NS = not significant.

Table 7. Summary of County Variety Demonstrations, 2020.

Cultivar	Plant Stand	Harvest Moisture	Test Weight	Grain Yield	Head Rice	Total Rice
	(plant/ft^2)	(%)	(lb/bu.)	(bu./ac)	(%)	(%)
CLL15	22.8 ab†	15.9	43.2	167.4 b	55.0	67.2
Diamond	22.2 b	16.1	43.7	171.2 ab	55.1	67.5
Jewel	24.5 a	16.2	43.3	175.8 a	55.5	67.9
P-value	0.0708	0.5029	0.4997	0.0763	0.7863	0.3605
CV‡	15.34	6.68	3.81	7.32	5.20	2.24
$LSD_{0.10}$‡	1.7	NS‡	NS	6.1	NS	NS

† Means within a column followed by the same letter are not significantly different ($P > 0.1$).

‡ CV = coefficient of variation; LSD = least significant difference; NS = not significant.

Performance of Ten Rice Cultivars in a Furrow-Irrigated Rice (FIR) System, 2020

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Abstract

In the last several years, there has been an increased interest in furrow-irrigated rice (FIR) (*Oryza sativa* L.) production. Cultivar selection recommendations have been general and primarily based on anecdotal evidence to date. In 2020, small-plot rice cultivar performance trials were established at two sites on silt loam soils. A split-plot design was utilized with the whole-plot factor being the location within the field (top and bottom) and the split-plot factor being the cultivar, of which there were ten evaluated. At both sites in 2020, the bottom area of the field had significantly higher yields than the top area of the field. In general, the hybrid cultivars RT XP753, RT 7521 FP, and RT 7301 had significantly higher yields than the other entries in the trials at both top and bottom areas of the fields. As plot areas were uniformly managed, additional research is necessary to determine whether varieties can be more competitive with hybrids when cultivar-specific management practices are implemented.

Introduction

In 2018 and 2019, over 100,000 acres utilized a furrow-irrigated rice (FIR) system in Arkansas. Preliminary estimates suggest that number to be greater than 200,000 acres in 2020. Limited research has been conducted on current rice cultivars for their performance in a FIR production system. Hybrid cultivars have been suggested as more reliable options in a FIR system due to their disease resistance traits and root systems, which may provide improved stress management. In addition, hybrid cultivars have been noted for their increased efficiency in nitrogen uptake compared to pure-line varieties (Norman et al., 2013), which may be increasingly beneficial in a FIR system. In general, hybrid cultivars are recommended in FIR systems primarily based on observation and anecdotal evidence.

Procedures

Field studies were located at 1 commercial farm in Monroe County and 1 University of Arkansas System Division of Agriculture research station in 2020. The commercial field site in Monroe County was a Foley-Bonn Complex and Calloway silt loam, while the Rice Research and Extension Center (RREC) site was a Dewitt silt loam (Table 1).

Both sites utilized a 30-in. furrow spacing. The small plot design was a split-plot, with the whole-plot factor being the location within the field (top, where upland conditions existed, and bottom, where flooded conditions generally existed) and split-plot factor being cultivar. Cultivars tested during 2020 included Diamond, Jewel, CLL15, CLL16, CLL17, Jupiter, Titan, RT XP753, RT 7521 FP, and RT 7301. Each plot was 4 beds in width and 17 ft in length. Approximately a 4- to 8-in. flood was held at the bottom of both sites, with the previous crop being soybean [*Glycine max* (L.) Merr.].

Field management was consistent with University of Arkansas System Division of Agriculture recommendations. Irrigation occurred every 4–7 days at each site. At maturity, a single bed row (30-in. harvest width) was harvested, the moisture content and weight of the grain were determined, and a subsample of harvested grain was removed for milling purposes. Grain yields were adjusted to 12% moisture and reported on a bushel per acre (bu./ac) basis. A bushel of rice weighs 45 lb. The dried rice was milled to obtain percent head rice (%HR, whole kernels) and percent total white rice (%TR) to provide a milling yield expressed as %HR/%TR. Data were analyzed using analysis of variance, PROC GLM using SAS v. 9.4 (SAS Institute, Inc. Cary, N.C.) with means separated using Fisher's least significant difference test ($P = 0.05$).

Results and Discussion

There was a location by cultivar interaction at both study sites ($P < 0.05$). Therefore, data were analyzed by location (top and bottom) at each study site. At Monroe Co. at the top of the field, RT 7521 FP, RT 7301, and RT XP753 had significantly higher grain yield compared to all other cultivars tested (Table 2). Jupiter had greater head rice yields than all other entries. At the bottom of the Monroe Co. site, similar to the top of the field, RT XP753, RT 7521 FP, and RT 7301 had significantly higher grain yields than all other cultivars tested. However, grain yield at the bottom of the field was much greater than at the top of the field. Titan and CLL15 had the highest head rice yields. Jewel, RT XP753, and RT 7301 had the highest total rice yields.

At the RREC site at the top of the field, RT 7521 FP, RT XP753, and RT 7301 had the highest grain yields (Table 3). Jupiter

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had the highest percent head rice of all cultivars. At the bottom of the field, there were no significant differences in grain yield, while CLL15, RT 7521 FP, RT 7301, and CLL16 had the highest numerical yields. Grain yield was greater at the bottom of the field compared to the top of the field. Jupiter and Titan had the greatest percent head rice, and Jewel, RT XP753, RT 7521 FP, and RT 7301 had the highest percent total rice.

Overall, grain yield was much greater at the bottom of the field, where a 4- to 8-in. flood was held from green ring to maturity. Milling yield was also generally higher and more consistent at the bottom of the field. The hybrid cultivars RT XP753, RT 7521 FP, and RT 7301 produced significantly higher grain yield than the other entries in the trials at both top and bottom areas of the fields. Plots were, however, uniformly managed to optimize hybrid rice production. Additional research is needed to determine whether varieties can be more competitive with hybrids when cultivar-specific management practices are implemented.

Practical Applications

The 2020 FIR cultivar performance trials provide additional data to producers interested in the FIR production system. The trials also provide valuable information on cultivar performance in the uppermost non-flooded area of the field versus the bottom end of the field where saturated soil conditions exist.

Acknowledgments

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Table 1. Agronomic information for furrow-irrigated rice cultivar trials in 2020.

	Monroe Co.	Rice Research and Extension Center
Soil Classification	Foley-Bonn Complex / Calloway silt loam	Dewitt silt loam
Planting date	6 May	16 May
Emergence date	15 May	22 May
Harvest date	11 September	30 September
Nitrogen management	Pre-irrigation: 46 lb N/ac 1 week later: 46 lb N/ac 2 weeks later: 46 lb N/ac 3 weeks later: 46 lb N/ac	Pre-irrigation: 130 lb N/ac 2 weeks later: 46 lb N/ac

Table 2. Results of Monroe County Furrow-Irrigated Rice Trial during 2020 (planted 6 May; harvested 11 September).

Cultivar	Grain Length[a]	Location	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
			(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	Top	0	11.1	110	46/66
Jewel	L	Top	0	12.2	124	58/72
CLL15	L	Top	0	11.1	113	58/70
CLL16	L	Top	0	15.9	132	59/72
CLL17	L	Top	0	12.8	128	61/68
Jupiter	M	Top	0	13.7	103	67/72
Titan	M	Top	0	11.2	121	35/68
RT XP753	L	Top	0	12.6	181	53/72
RT 7521 FP	L	Top	0	13.4	190	61/72
RT 7301	L	Top	0	12.7	187	53/72
$LSD_{0.05}$[e]	--	--	--	1.2	28	6/NS[f]
Diamond	L	Bottom	0	15.1	222	61/70
Jewel	L	Bottom	0	16.0	221	66/73
CLL15	L	Bottom	0	15.4	223	68/71
CLL16	L	Bottom	0	18.0	227	64/71
CLL17	L	Bottom	0	15.6	224	65/70
Jupiter	M	Bottom	0	19.3	221	66/69
Titan	M	Bottom	0	15.5	224	69/72
RT XP753	L	Bottom	0	13.2	263	64/73
RT 7521 FP	L	Bottom	0	16.7	261	66/70
RT 7301	L	Bottom	0	13.7	244	65/73
$LSD_{0.05}$	--	--	--	1.2	21	3/2

[a] Grain length: L = long-grain; M = medium-grain.
[b] Lodging = % of plot down at harvest.
[c] Grain moisture at harvest.
[d] Milling yield = % Head Rice/% Total Rice.
[e] LSD = least significant difference.
[f] NS = not significant.

Table 3. Results of Arkansas Co. Furrow-Irrigated Rice Trial during 2020 (planted 16 May; harvested 30 September).

Cultivar	Grain Length[a]	Location	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
			(%)	(%)	(bu./ac)	(%HR/%TR)
Diamond	L	Top	0	13.1	86	42/65
Jewel	L	Top	0	12.8	67	43/66
CLL15	L	Top	0	12.2	84	49/67
CLL16	L	Top	0	13.0	83	42/64
CLL17	L	Top	0	12.0	106	51/67
Jupiter	M	Top	0	14.8	105	59/68
Titan	M	Top	0	12.1	89	46/64
RT XP753	L	Top	0	11.9	147	50/70
RT 7521 FP	L	Top	0	11.7	148	44/67
RT 7301	L	Top	0	12.2	137	50/70
$LSD_{0.05}$[e]	--	--	--	0.8	23	5/NS[f]
Diamond	L	Bottom	0	13.1	159	58/70
Jewel	L	Bottom	0	13.1	166	61/71
CLL15	L	Bottom	0	14.6	177	58/69
CLL16	L	Bottom	0	11.9	176	57/70
CLL17	L	Bottom	0	13.8	152	58/68
Jupiter	M	Bottom	0	12.8	161	65/69
Titan	M	Bottom	0	12.7	156	63/70
RT XP753	L	Bottom	0	13.3	169	59/71
RT 7521 FP	L	Bottom	0	12.3	177	60/71
RT 7301	L	Bottom	0	12.3	177	59/71
$LSD_{0.05}$	--	--	--	NS	NS	3/2

[a] Grain length: L = long-grain; M = medium-grain.
[b] Lodging = % of plot down at harvest.
[c] Grain moisture at harvest.
[d] Milling yield = % Head Rice/% Total Rice.
[e] LSD = least significant difference.
[f] NS = not significant.

Water Use and Yield Differences in Farmer-Managed Furrow Irrigated and Multiple Inlet Rice Irrigation Levee Flooded Fields

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Abstract

A study was conducted to evaluate the difference in irrigation water use and yield of paired fields using Multiple Inlet Rice Irrigation (MIRI) and Furrow Irrigated Rice (FIR). Paired farmer-managed fields (n = 20; n = 22) were compared with the same soil type and cultivars between 2016 and 2020. No difference in irrigation water use ($P = 0.27$) was found, but FIR fields had a significantly lower yield of 16.7 bu./ac ($P = 0.001$).

Introduction

In the United States, Arkansas is the largest producer of rice. In 2019, Arkansas rice producers harvested 1,126,000 acres with an average yield of 167.7 bu./acre (USDA-NASS, 2019). This represents 45.6% of total U.S. rice produced and 47.1% of the total acres planted with rice in the U.S. (Hardke, 2019).

Irrigation is one of the more important inputs for obtaining maximum yield in furrow-irrigated rice. Among row crops in the U.S., rice is one of the largest users of water resources. For farmers in Arkansas, much of the irrigation water is provided by groundwater, and much of that is from the Mississippi River Alluvial aquifer. However, the groundwater levels throughout the Mississippi River Alluvial aquifer are declining. One study found an average decline of 1.44 ft in wells across the aquifer for the 2012–2013 season (Arkansas Natural Resource Commission, 2014).

The most common system of irrigation for rice in Arkansas is flooding (Vories et al., 2002). The three primary types of flood-irrigated rice production systems are cascade flood, Multiple Inlet Rice Irrigation (MIRI), and Alternate Wetting and Drying (AWD). In flooded rice production systems, paddies are formed at intervals in order to hold a shallow flood of 3–6 inches during the growing season. Cascade flooding involves the use of levee spills and uses gravity to convey water from one paddy to the other via the levee spills or gates. The MIRI uses lay-flat irrigation pipe and holes and gates placed at each paddy to uniformly distribute water to each paddy. The AWD utilizes MIRI but allows the flood to subside before the paddies are reflooded. Cascade fields use on average 32 ac-in./ac of water in one growing season (Henry et al., 2013), where MIRI fields are expected to only require 24 ac-in./ac due to the improved ability to add water to each paddy concurrently and capture rainfall.

In 2019 there was a 10% increase in acreage being furrow-irrigated for rice (Hardke and Chlapecka, 2020). Other than the water-saving benefits, there are other advantages associated with growing furrow-irrigated rice. These include savings in levee construction and removal, easier access to the field during harvest, and a reduction in greenhouse gas emissions (Vories et al., 2002; Adhya et al., 2014). Also, due to quick drying of the field, it is easier to use ground equipment for operations such as fertilization and chemical treatments which can significantly reduce the total production cost. One disadvantage is that some studies have found a yield reduction when using FIR (Vories et al., 2002; Singh et al., 2006). FIR rice has the potential to greatly impact rice production.

Procedures

Cooperators were identified by county Extension agents, and paired fields were located with cooperators. Fields were planted within 3 days of each other to the same variety. Soil types were the same texture. Portable propeller flow meters (McCrometer, Hemet, Calif.) were installed before the first irrigation. Harvest yields were collected from cooperators at the end of the season from production records for each field in the study. Data were analyzed using JMP Pro 15 (SAS Institute, Inc., Cary, N.C.) using analysis of variance and Dunnett's Method for multiple comparison test with an alpha of 0.05 and MIRI as the control for equal variances. If variances were unequal, the Wilcoxon test was used.

Results and Discussion

Soil types in the study were clay (14), silt loam (8), and sandy loam fields (2). All but 2 paired fields used hybrid rice varieties. There were 4 FIR fields in 2016, 4 in 2017, 3 in 2018, 3 in 2019, and 8 in 2020. There were 4 MIRI fields in 2016, 2 in 2017, 3 in 2018, 4 in 2019, and 8 in 2020. There were more FIR fields than MIRI fields making the dataset unbalanced. Thus, yields and water use data are heavily weighted to weather and production issues for that year. Data from 2016 to 2020 shown in Table 1 resulted in 20 MIRI fields and 22 FIR fields (more FIR fields were sampled than

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MIRI fields at one grower's operation). The average yield of MIRI was 202.9 bu./ac and 186.2 bu./ac for FIR and was significantly different ($P = 0.001$) by 16.7 bu./ac. The average water use was not significantly different ($P = 0.27$), with 23.9 ac-in./ac for FIR fields and for 28.0 ac-in./ac for MIRI fields.

There is considerable variation in the data in both yield and water use, and the data was not consistent as the FIR fields were not always lower yielding than MIRI fields; sometimes, the FIR fields had higher yields and water use than the paired MIRI field. About one eighth of the data is represented by less experienced growers and about half of the data was taken from a single grower who provided multiple data points every year in the study.

The study demonstrates that FIR uses nearly the same amount of water as a MIRI field, although numerically it was almost 4-in less. Overall on average, growers experienced a significant yield penalty in FIR fields compared to their FIR fields. It should be noted that many of the farmers that had participated in the study were new FIR growers. No public recommendations existed at the beginning of the study to aid growers starting to use the FIR production system, but since that time, more has been published on the subject (Hardke et al., 2017; Hardke et al., 2019). As growers develop more experience with this type of production system, it is anticipated that rice farmers will likely see an improvement in yield potential and water use as experience with FIR continues. Also, soil moisture monitoring was provided to many of the participants, but few used the technology. It was observed on several occasions with fields that had monitors that fields experienced a period of drier soil conditions, usually between green ring and boot and in some cases, very dry soil conditions. Only one field in the study used surge irrigation. Most FIR fields were being irrigated on a calendar method or irrigated when irrigation capacity was available, so additional gains in water management may be available through soil moisture monitoring, surge irrigation, and pit-less tailwater recovery. The MIRI data is consistent with the 24 ac-in/ac of irrigation water use expected by MIRI fields reported by Vories et al. (2006) and Henry et al. (2013).

Practical Applications

It has long been unknown how much irrigation water is used for FIR and, on average, whether a yield penalty exists for FIR production system. This study provides a baseline for understanding the overall profitability of FIR relative to MIRI. While there was a yield penalty observed, there are also additional production costs in a MIRI system that may offset the revenue difference between FIR and MIRI production systems. As rice growers become more experienced with FIR production, the yield penalty will likely become less, and irrigation water use further reduced. The benefits of no-till, cover crops, earlier planting opportunities, surge irrigation, soil moisture monitoring, and other agronomic practices are opportunities to close the yield gap and reduce irrigation water needs that warrant further study.

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Table 1. Yield and water use averages, standard error, and 95% confidence interval for furrow irrigated rice (FIR) and multiple inlet rice irrigation (MIRI).

Year	County	Soil Type	Furrow Irrigated Rice Yield	MIRI Yield	FIR Irrigation Water use	MIRI Irrigation Water use
			(bu./ac)	(bu./ac)	(ac-in./ac)	(ac-in./ac)
2016	Arkansas	**Silt loam**	179	213	29.5	52.6
2016	Clay	**Clay**	172	156	15.6	17.1
2016	Clay	**Clay**	175	202	18.2	20.6
2016	Jefferson	**Clay**	164	176	11.6	14.3
2017	Clay	**Sandy loam**	185	200	12.8	18.1
2017	Clay	**Sandy loam**	185		22.3	
2017	Clay	**Clay**	189		20.5	
2017	Green	**Silt loam**	200	211	44.4	21.6
2018	Green	**Silt loam**	190	223	24.6	39.8
2018	Jackson	**Silt loam**	190	217	21.3	25.4
2018	Clay	**Clay**	202	215	32.55	35.7
2019	Clay	**Clay**	189	218	17.7	23.29
2019	Clay	**Clay**	195	206	18.67	21.17
2019	Clay	**Clay**	192	220	18.185	15.82
2020	Lawrence	**Silt loam**	199	210	29.2	57.33
2020	Clay	**Clay**	175	215	31.3	26.78
2020	Jefferson	**Silt loam**	205	228	23.12	11.14
2020	Arkansas	**Silt loam**	173	165	37.29	50.68
2020	Craighead	**Silt loam**	210	230	35.7	17.06
2020	Clay	**Clay**	184	192	29.6	23.11
2020	Clay	**Clay**	190	204	26.97	47.27
2020	Jackson	**Silt loam**	152	156	5.54	21.27
Average			186.2	202.9	23.9	28.0
Standard Error			3.95	4.14	2.51	2.63
95% CI			178.2–194.2	194.5–211.2	18.8–29.0	22.6–33.3

Grain Yield Response of Furrow-Irrigated Hybrid RT 7521 FP to Environmentally Smart Nitrogen (ESN) and Fertigation Using Water Soluble Fertilizers

C.G. Henry,[1] J.P. Pimentel,[2] P.N. Gahr,[1] and T. Clark[1]

Abstract

Two studies were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., on a DeWitt silt loam. One evaluated the performance of 3 different nitrogen (N) fertilizer sources, and the other evaluated the yield between till and no-till in a furrow-irrigated rice field. The N sources used were 32% urea-ammonium nitrate (UAN) solution, Environmentally Smart Nitrogen (ESN), and urea. The N sources were used in several different split application timings. No yield differences between the N treatments were observed for the hybrid RT 7521 FP. There was no significant difference in yield between no-till and tillage treatments.

Introduction

In the United States, Arkansas is the largest producer of rice. In 2019, Arkansas rice producers harvested 1,126,000 acres, and the state average yield was 167.7 bu./ac (USDA-NASS, 2019). This represents 45.6% of total U.S. rice produced and 47.1% of the total acres planted to rice (Hardke, 2019). In Arkansas, 7.1% of the rice acreage is furrow-irrigated, and it is gaining popularity among farmers because it helps to simplify crop rotation and management as well as reduced labor.

Nitrogen (N) is the most important and limiting nutrient in irrigated rice production to obtain maximum yields. In flood-irrigated rice, N fertilization can be done as a single application when the plants are at the 4- to 6-leaf stage, or it can be split into 2 applications, one at the 4- to 6-leaf stage and the second at the beginning of the reproductive stage (Frizzell et al., 2016; Wilson et al., 1994). Nitrogen fertilization in furrow-irrigated rice (FIR) is less understood than in the flooded rice production system.

Little is known about N efficiency in FIR. Because it is readily available as a liquid, urea-ammonium nitrate (UAN) can be applied through the irrigation system, likely at a much lower cost than dry fertilizers in FIR systems. Another approach to increase N efficiency is to use controlled release fertilizers like Environmentally Smart Nitrogen (ESN). These types of fertilizers can help to reduce environmental losses by matching the nutrient demand of crops with N release from the fertilizer (Blackshaw et al., 2011).

Little is known about no-till furrow-irrigated rice. Henry et al. (2020) conducted a study in a furrow-irrigated-rice system and found no significant difference between the tillage and no-till treatments.

This experiment was done to study the effects on the yield of 3 different kinds of N fertilizers using various different application methods in a FIR field. An evaluation of tillage versus no-tillage in FIR was also done.

Procedures

These studies were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, in 2020. The soil in the field is predominantly a DeWitt silt loam. The field has been in continuous FIR since 2016 and no-till since 2017. Raised beds were constructed on 30-in. spacing using a bedder-roller in 2017 and kept intact for fertilizer, fertigation, no-till, and irrigation studies. A furrow runner (Perkins Sales, Bernie, Mo.) was then used to reconstruct a narrow furrow leaving the bed intact. For the tillage study, the soil was cultivated, and then the beds were reconstructed.

Gramaxone (40 oz/ac) was used to kill any vegetation before planting. RiceTec 7521 Full Page (RT 7521 FP) was seeded in the field. The field was divided into a total of 42 plots of approximately 1 acre for each treatment. Each plot consisted of 12 beds and 12 furrows (11 plus 2 half furrows). Each treatment was replicated 3 times in a randomized design. Rice was seeded at 27 lb/ac on 13 and 14 May.

ESN Study: The following are the N treatments utilizing urea and ESN.

- ESN (170)–170 lb N/ac as ESN on 13 May as a pre-plant application.
- Urea (170)–170 lb N/ac as urea with a urease inhibitor on 13 June at the 3–4 leaf stage.
- Split Urea/ESN (150/30)–150 lb N/ac as urea with a urease inhibitor applied on 13 May at pre-plant then 30 lb N/ac as ESN applied on 13 June at the 3–4 leaf stage at the top only.
- Split Urea/Urea (150/30)–150 lb N/ac as urea with a urease inhibitor applied on 13 May as a pre-plant then 30 lb N/ac as urea with a urease inhibitor applied on 13 June at the 3–4 leaf stage at the top only.

The fertigation fertilizer study consisted of a split-plot design and a filler block where water-soluble fertilizers could be ap-

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plied in a large scale to the study field. Twenty-seven acres were irrigated using the technique described. A split-plot design was used to evaluate the boot nitrogen application.

- No-Boot–50 lb N/ac as UAN applied on 18 and 29 June, and 6 July using fertigation for a total of 150 lb N/ac as UAN.
- Boot–50 lb N/ac as UAN applied on 18, 29 June and 6 July using fertigation, then 20 lb N/ac as UAN fertigated on 27 July at boot stage for a total of 170 lb N/ac as UAN.

The fertigated UAN was done using a modified Chemigation Valve (Fresno Valves and Casting inc. Lubbock, Texas) model CT100 installed with a lay-flat pipe to input fertilizer together with irrigation to provided backflow prevention, air relief, and drain back. An Inject-O-Meter Mfg. Co., Inc. pump was used to meter fertilizers. The advance time of the irrigation was determined from previous knowledge of advance time in earlier irrigation events. Historically, the advance time of the field was 10 h. The fertigation system was adjusted to deliver the application rate desired in 7 h. The fertigation system was started 3 h after the initiation of the irrigation. After the wetting front advance, the irrigation was terminated, allowing for recession to deliver fertilizer to the tail end of the furrow. The next morning, irrigation recommenced incorporating the UAN into the profile.

Additional micronutrient fertilizers were applied as deficiencies indicated according to tissue analysis both Campbell (2000) and Bell et al. (1996) were used as a guideline to determine deficiencies. Specifically, deficiencies or nearly deficient nutrients, including calcium, magnesium, potassium, and manganese were noted and supplemented in very small amounts in separate fertigation applications to the N applications. The field was furrow-irrigated with a novel tailwater recovery system (Kandpal 2018). The system applied 12.2 ac-in./ac of irrigation to the entire field during the season with an additional 16.6 in. of rainfall. The ESN and urea treatments were not continuously irrigated until after boot. Irrigation was shut off by way of a line valve to the ESN and urea study to provide dry down periods to represent the wet-dry cycle experienced in a typical FIR field. This occurred for 5–7 days when fertigation events were done on fertigation treatments, and then the field was continuously irrigated a week after boot. It is assumed that any N losses that would occur from wetting and drying would have occurred by the time the rice reached the boot stage. End blocking was used to hold a flood on the bottom of the field and allow minimal runoff. Irrigation was applied continuously to the fertigation treatments and tillage studies using lay-flat pipe.

A herbicide application with 16 oz/ac of Command, 2 oz/ac of Sharpen, and 1 qt/ac of glyphosate was applied preemergence the same day of planting on 13 May. The first herbicide postemergence spray application was made on 2 June with 30 oz/ac of Ricestar HT and 16 oz/ac of Command. The second herbicide postemergence spray application was made on 14 June with 2 oz/ac of Gambit, 6 oz/ac of Preface, and 2 pt/ac of Basagran. Aerial application of 21 oz/ac of Quilt Xcel fungicide was made on 27 July.

A GreenSeeker (Trimble) device was used to measure the Normalized Difference Vegetation Index (NDVI) of randomly selected areas of the plant canopy as well as reference strips in each plot during the panicle initiation stage. A reference strip of 10 ft by 1300 ft with an application rate of over 300 lb N/ac was placed next to the fertigation plots. The reference plot was used to determine nitrogen needs by comparing tissue samples from the reference strip to the fertigation plots. Normalize Difference Vegetation Indices (NDVI) readings were also collected and compared between the reference strip and fertigation treatments. The highest response index value measured was 1.08.

Analysis of variance was performed using JMP Pro. The measured outcomes were tested by the assumptions of the mathematical model (normality and homogeneity of variance). The factor means for each response variable, when significant, were compared by Tukey's honestly significant difference test at a 5% probability.

Results and Discussion

It should be noted that because of the variable flow tailwater recovery system, the fertigation study maintained soil moisture conditions between saturation and field capacity of the silt loam soil. The ESN and urea study were allowed to dry down on several occasions while fertigation applications were being completed and for some additional days to simulate a conventionally furrow-irrigated field, but likely stayed very near field capacity during the entire season.

No significant yield difference was found between the 2 ESN and 2 urea treatments (Table 1). The data does not clearly indicate that any fertilizer treatment or split is more advantageous over another. The highest yield was observed in the urea and split urea/ESN treatments with 200.0 bu./ac and 199.0 bu./ac, respectively.

When comparing the results of fertigation treatments, there was no significant difference (P = 0.47) between the treatments (Table 2) of the boot N treatment yield average of 207.2 bu./ac and no-boot treatment of 210.8 bu./ac. The results indicate that there was no benefit from a boot N application and that 150 lb N/acre is sufficient.

It should also be noted that all of the first application of nitrogen (50 lb N/ac) occurred 19 June, a day after the "final recommended time to apply preflood N if early N delayed" in the DD50 program. The subsequent applications of N (50 lb N/ ac) occurred on 29 June and 6 July. Boot N for the boot treatment was applied on 20 July (20 lb N/ac), just ahead of the timeframe specified in the DD50 program (23–30 July) because the rice was in the boot stage. With fertigation, N applications may have a wider window for application, and it is practical to provide N at each irrigation event during the vegetative phase. While not directly comparable, the ESN/urea study and the fertigation study were adjacent, and the yields of the fertigation plots were 7–11 bu./ac higher.

Fertigation was governed by the weather and plant tissue analysis. The first UAN application of 50 lb N/ac was delayed (shown in Fig. 1) compared to when the latest preflood urea application would normally take place. Then the second was also later than intended and occurred after green ring when tissue samples were decreasing. However, the second and third applications of 50 lb N/ac increased the tissue N concentration and was adequate to maximize yield in the study. The tissue N concentration at the time of boot was already decreasing, and the additional application at boot did not translate into an increase in grain yield.

For the till vs. no-till study, there was no significant difference ($P = 0.525$; Table 3). The tillage study provided the same result as in 2019 on the same plot, which also found no significant difference between yields. After the first year (2018) in a no-till system, no significant difference in yield has been observed, suggesting that tillage does not provide any yield advantage.

Practical Applications

The practice of using ESN pre-plant provides a unique benefit to the furrow irrigated rice grower by concentrating fertilizer applications to the field into one pass. Being able to apply all nitrogen needs before planting with no yield penalty has the benefit of reduced workload later in the season. It was also observed that the ESN treatments canopied faster and were greener at the 4- to 5-leaf stage, which may be a benefit not assessed in this study. Additional work to determine an optimum rate of ESN is warranted for the FIR system.

The practice of fertigation also provides a unique benefit to the FIR system because fertigation is less sensitive to soil moisture conditions and loss mechanisms from wet soils. The soil was allowed to dry (continuous flow irrigation was stopped) for 2–4 days before fertigation events so that the intake rate of the soil was adequate for initial abstraction to occur. Later applications of N are practical in the FIR system using fertigation, providing flexibility to the furrow-irrigated grower. Thus this approach could be used to "catch up" to a low tissue N condition and addressed the deficiency in the subsequent irrigation.

This study demonstrated that many different fertilizer approaches could be successful in a FIR production system. It appears that if adequate N is provided early enough in the growth cycle, then additional applications will not result in a yield benefit.

The tillage study suggests that no-till may be feasible with no yield penalty in a FIR system.

Acknowledgments

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Table 1. Yield differences between nitrogen source and application timing revealed by analysis of variance.

Treatment	Yield
(lb N/ac)	**(bu./ac)**
ESN† (170)†	192.7 a‡
Urea (170)†	199.9 a
Split Urea/ESN (150/30)†	199.0 a
Split Urea (150/30)†	196.6 a

† ESN = Environmentally Safe Nitrogen; Urea applied at 4-6 leaf; Urea applied at 4-6 leaf, ESN applied on the top half only at 4–6 leaf; split Urea applied with additional application on the top half only all at 4–6 leaf.

‡ Means within a column followed by different letters are significantly different at P = 0.05 level. Tukey's honestly significant difference method was used for mean comparison.

Table 2. Yield differences between boot and no-boot treatments by analysis of variance.

Treatment	Yield
(lb N/ac)	**(bu./ac)**
Boot (170)†	207.2 a‡
Control/No-boot (150)†	210.8 a

† 150 lb N/ac applied prior to boot (control), boot received additional 30 lb N/ac at boot growth stage.

‡ Means within a column followed by different letters are significantly different at P = 0.05 level. Tukey's honestly significant difference method was used for mean comparison.

Table 3. Grain yields of tilled and no tillage treatments in bushels per acre from 2018 to 2020.

Year	Conventional Tillage	No-Till	*P*-Value
2018	117.9 a†	95.2 b	0.02
2019	216.1 a	209.4 a	NS, 0.52‡
2020	202.2 a	192.2 a	NS, 0.53‡
3-yr Average	178.8 a	165.6 a	NS, 0.29‡

† Means within a column followed by different letters are significantly different at P = 0.05 level. Tukey's honestly significant difference method was used for mean comparison.

‡ NS = not significant.

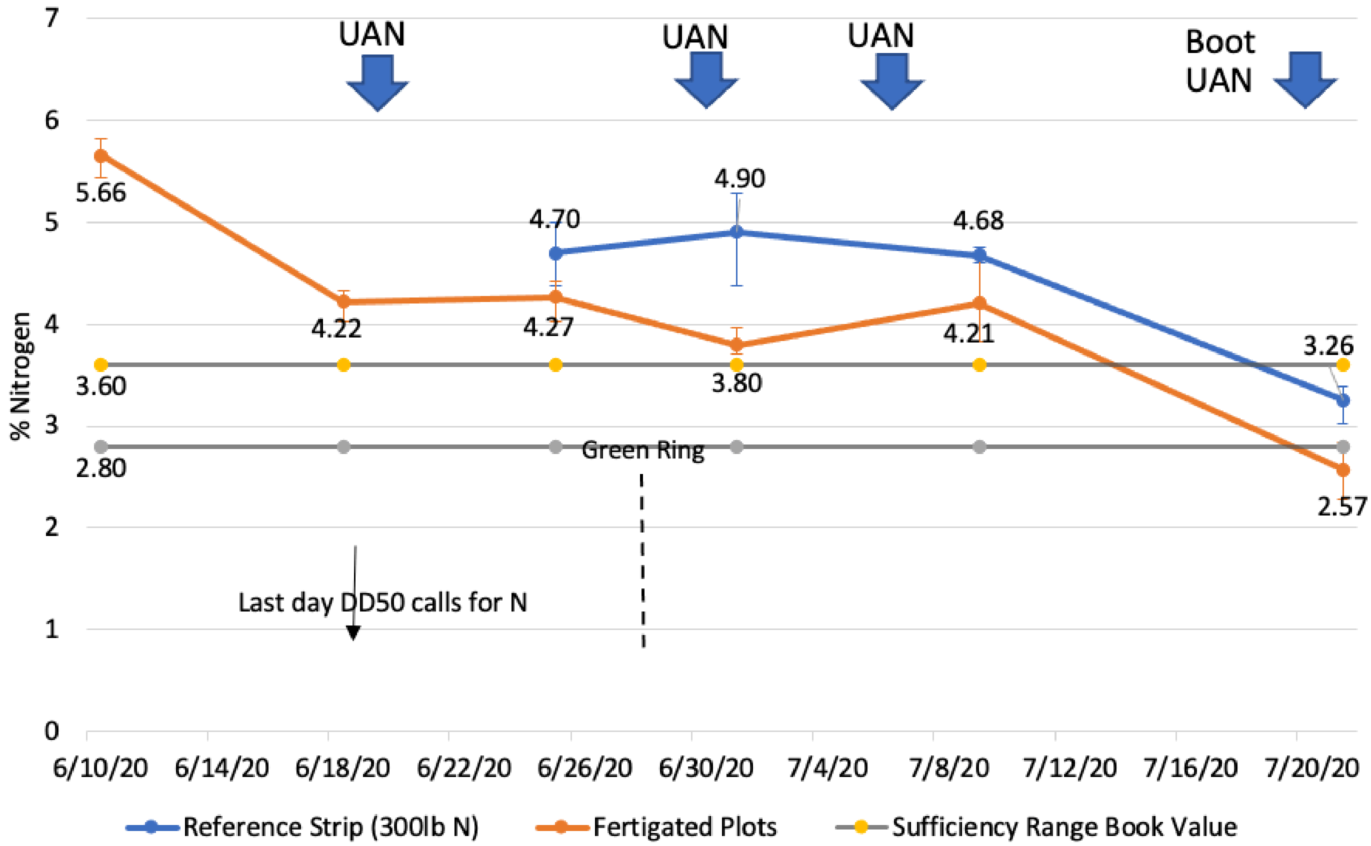

Fig. 1. Plant tissue nitrogen concentration of fertigation treatment and reference plot and urea-ammonium nitrate applications.

Evaluating Irrigation Timing, Depletion, Water-use and Efficiencies in Furrow Irrigated-Rice

C.G. Henry,[1] J.P. Pimentel,[2] P.N. Gahr,[1] and T. Clark[1]

Abstract

A study was conducted to evaluate the performance of 4 different irrigation timings in furrow-irrigated rice at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Arkansas, on a Dewitt silt-loam soil. The irrigation timings were 1) continuously irrigated, 2) irrigation every 3 days, 3) irrigation every 7 days, and 4) irrigation every 10 days. Application depths of 1 ac-in./ac for 24 hours were applied. No significant difference in yield was found between treatments ($P = 0.4$). The variable flow tailwater system had a significantly higher water use efficiency (6.6 bu./in.) than the other treatments and the lowest irrigation water use (12.2 ac-in./ac), even less than the 10-day treatment (5.53 bu./in. and 14.9 ac-in./ac).

Introduction

In the United States, Arkansas is the largest producer of rice. In 2019, Arkansas rice producers harvested 1,126,000 acres with an average yield of 167.7 bu./ac (USDA-NASS, 2019). This represents 45.6% of total U.S. rice produced and 47.1% of the total acres planted with rice in the U.S. (Hardke, 2019).

Irrigation is one of the more important inputs for obtaining maximum yield in furrow-irrigated rice (FIR). Among row crops in the U.S., rice is one of the largest users of water resources. For farmers in Arkansas, much of the irrigation water is provided by groundwater, and much of that is from the Mississippi River Alluvial aquifer. However, the groundwater levels throughout the Mississippi River Alluvial aquifer are declining. One study found an average decline of 1.44 ft in wells across the aquifer for the 2012–2013 season (Arkansas Natural Resource Commission, 2014).

The most common system of irrigation for rice in Arkansas is flooding (Vories et al., 2002). Flood irrigation uses about 24 to 32 ac-in./ac of water in one growing season (Henry et al., 2013). Some other irrigation methods, like alternate wetting and drying and furrow irrigation, have started to gain interest. In 2019 there was a 10% increase in acreage using furrow irrigation for rice (Hardke and Chlapecka, 2020). Other than the water-saving benefits, there are other advantages associated with growing FIR. These include savings in levee construction and removal, easier access to the field during harvest, and a reduction in greenhouse gas emissions (Vories et al., 2002; Adhya et al., 2014). Also, due to quick drying of the field, it is easier to use ground equipment for operations such as fertilization and chemical treatments which can significantly reduce the total production cost. One disadvantage is that some studies have found a yield reduction when using furrow irrigation (Vories et al., 2002; Singh et al., 2006). Furrow-irrigated rice has the potential to greatly impact rice production. Because of this, it is important to study the different methods and technologies to improve production using FIR.

This experiment was done to evaluate the performance of 4 different irrigation timing on the crop yield and irrigation efficiencies in a FIR system.

Procedures

This study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, in 2020. The soil in the field is predominately a DeWitt Silt loam, which was identified by soil tests conducted by the USDA web soil survey. The field has been in continuous FIR since 2016 and no-till since 2017 (last year of tillage). Raised beds were constructed on 30-in. spacing using a bedder-roller in 2017, and a Perkins furrow runner was used to reconstruct a narrow furrow while leaving the beds intact.

Gramaxone (40 oz/ac) was used to kill any vegetation before planting. RiceTec 7521 Full Page (RT 7521 FP) was seeded in the field. The field was divided into a total of 12 plots of approximately 1 acre each. Each plot consisted of 12 beds and 12 furrows (11 plus 2 half furrows). Each treatment was replicated 3 times in a randomized design. The rice was seeded at a rate of 530,000 seeds per acre or 27 lb/ac on 13 and 14 May.

A herbicide application with 16 oz/ac of Command, 2 oz/ac of Sharpen, and 1 qt/ac of glyphosate was applied pre-emergence the same day as planting on 13 May. The first herbicide post-emergence application was made on 2 June with 30 oz/ac of Ricestar HT and 16 oz/ac of Command. The second herbicide post-emergence application was made on 14 June with 2 oz/ac of Gambit, 6 oz/ac of Preface, and 2 pt/ac of Basagram. Aerial application of 21 oz/ac of Quilt Xcel Fungicide was made on 27 July.

The field was furrow-irrigated with a novel patented tailwater recovery system referred to as a pit-less variable flow tailwater recovery system (VFTWRS) (Kandpal, 2018; Henry et al., 2019). Irrigation events used the tailwater when available, and irrigation water was only added to the system when the water was no longer available to return. Twelve-inch diameter lay-flat pipe

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(Delta Plastics, Little Rock, Ark.) was used for irrigating the field and returning the tailwater to the top of the field. The appropriate diameter of the holes was determined using Pipe Hole And Crown Evaluation Tool (PHAUCET). Flow was monitored with McCrometer propeller meters (Helmuth, Calif.) for the inflow supply. All flow volumes were recorded by manual readings before and after events. Water use efficiency (WUE) was calculated as bu./in. by dividing yield per acre of each plot by water used (ac-in./ac) plus rainfall (in.) throughout the irrigation season. End blocking was used to hold a flood on the bottom of the field and allow minimal runoff to a maximum depth of 8 in.

An Aquatrac (AgSense, Huron, S.D.) and Time Domain Reflectometer sensor (Acclima, TDR-315L) were used to monitor the soil moisture in each treatment during the season and to calculate the volumetric water content. The Water Retention Curve for the Dewitt silt loam soil was made using a HYPROP (Hydraulic Property Analyzer, Meter Group, Pullman, Wash.), the field capacity was determined to be 35.6% volumetric water content (VWC), the wilting point was determined to be 8.9% VWC, and the available water content was calculated to be 26.7% VWC. These numbers were utilized to determine the allowable depletion.

Rainfall was accumulated from 22 May until 27 August, totaling 13.81 in. However, near drain time, an additional 2.74 in. was received from a hurricane weather pattern, resulting in a total of 16.55 in., which was used with the respective irrigation volumes to determine total water use efficiency (WUE). It should be noted that the 2.74 in. of rainfall likely did not contribute to yield, and the actual WUEs reported are likely higher than reported. Some lodging occurred in some of the plots as a result of the hurricane winds.

The study was divided into 4 treatments: continuous irrigation, and irrigation every 3, 7, and 10 days. Each treatment was irrigated for 24 hours per irrigation event resulting in a 1 ac-in./ac application. Plugs were used to ensure that only the treatments that were scheduled to be irrigated were irrigated. Water use for the field was measured at the inlet. The water use measured at the field inlet was used to characterize the water use of the variable flow tailwater recovery system. The irrigation study water use was measured using a reverse propeller in-line meter. The meter readings were recorded before and after each irrigation event and totalized for each treatment. Thus, the continuously irrigated treatment has 2 water applications, the total net irrigation applied to the field (water use of the variable flow tailwater recovery system), and the irrigation volume applied to the treatment plots representing if no tailwater system was used. The continuous treatment represents tailwater stored at the bottom of the field being returned nearly without interruption to the crown of the field. The pipeline pressure at the polypipe ranges between 0.5 ft of head in low flow conditions (200 gpm) as tailwater storage is being depleted to 2.5 ft of pressure when irrigation water and tailwater are being applied (900 gpm).

Analysis of variance was performed using R Software v. 3.4.2 and JMP Pro 15 (SAS Institute, Inc., Cary, N.C.). The measured outcomes were tested by the assumptions of the mathematical model (normality and homogeneity of variance). The factor means for each response variable, when significant, were compared by Tukey's honestly significant difference test at a 5% probability.

Results and Discussion

Table 1 shows the results for yield, volume water content, and allowable depletion between irrigation timings. The highest value for water use was found in the continuous treatment at 34.9 ac-in./ac, while the lowest was for the variable flow tailwater system at 12.2 ac-in./ac. This difference (nearly 3×) represents the improvement in water savings that could be expected from using the tailwater pump and trying to maintain well-saturated conditions similar to flooded rice production systems. The 3-d treatment used 23.1 ac-in./ac of irrigation while the 7-d used 16.2 ac-in./ac and the 10-d used 14.9 ac-in./ac. The continuous treatment is similar to what is expected from a flooded irrigation system, while the 3-d is similar to what is expected from a multiple inlet irrigation system. While the 10-d used the least amount of irrigation, it was still nearly 3-in. more than the variable flow tailwater system, suggesting that even a very delayed irrigation schedule may not be able to achieve the water savings from a variable flow tailwater system.

Irrigation treatments were applied based on the calendar, but the moisture content before each irrigation was determined and the subsequent allowable depletion was determined for each irrigation event (Table 1). The continuous irrigation treatment had the highest average VWC just before irrigation at 41.5%, well above field capacity, and the 7-d treatment had the lowest at 24.7%. The continuous treatment never fell below the field capacity and essentially was a negative or 0% depletion. The average allowable depletion (depletions averaged for all irrigation events) for the 3-d treatment was 11%, and the highest recorded allowable depletion was 41%. For the 7-d treatment, the average depletion was 41%, and the maximum was 79%; the 10-d treatment average depletion was 38%, and the maximum was 65%. The 7- and 10-d treatments may have experienced some water stress since at least 1 allowable depletion exceeded the 50% assumed stress accumulation level.

Table 2 shows the total water use efficiency between irrigation timings. The variable flow tailwater recovery system had the highest WUE of 6.6 bu./in. and was significantly higher than the 7-d (5.63 bu./in.) and 10-d treatments (5.53 bu./in.). The 3-d and continuous treatment (without the benefit of the tailwater return system) resulted in the lowest WUE's of 4.53 bu./in. and 3.68 bu./in., respectfully.

The highest yield (Table 1) was observed in the 3-d irrigation treatment, which had an average yield of 184.5 bu./ac. The continuous irrigation treatment yielded 179.5 bu./ac, the 7-d 170.5 bu./ac, and the 10-d 165.9 bu./ac, but none of the yields were significantly different ($P = 0.4$).

Practical Applications

In summary, very respectful yields were achieved with very high WUE, even for a later planted hybrid rice furrow irrigated system. Allowable depletions measured in this experiment indicate that rice can tolerate very high allowable depletions with no significant yield penalty. The study suggests that even if very high deficits are experienced from delayed or inadequate irrigation that yields will likely not be significantly reduced in a furrow irrigation production system. Very low gross irrigation volumes were realized with the variable flow tailwater recovery system, reducing water use by nearly 3 times compared to a common 3-d irrigation schedule. Extending irrigation past a 3-d cycle or up to a 40% average allowable depletion did not significantly reduce grain yields.

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Table 1. Yield, average percent volume water content before irrigation, average percent volume water content range, and highest allowable depletion just before irrigation from 4 different treatments; continuous irrigation, 3-day irrigation event spacing, 7-day irrigation event spacing, and 10-day irrigation event spacing.

Treatment	Yield	% Volume Water Content Before Irrigation Event	% Volume Water Content Range	Highest Allowable Depletion just before irrigation
	bu./ac	(AVG)	(AVG)	(%)
Continuous	179.5 a[†]	41.5	39–43	0
3 day	184.8 a	32.8	24.7–37.1	11
7 day	170.5 a	24.7	14.6–37.8	41
10 day	165.9 a	25.7	18.3–34.8	38

[†] Means within a column followed by different letters are significantly different at *P* = 0.05 level. Tukey's honestly significant difference method was used for mean comparison.

Table 2. Irrigation water use (ac-in./ac) water use efficiency in bu./ac-in. from irrigation treatments; continuous irrigation, 3-day irrigation event spacing, 7-day irrigation event spacing, and 10-day irrigation event spacing.

Treatment	Water Use	Water Use Efficiency
	(ac-in./ac)	(bu./in.)
Continuous (VFTWRS)[†]	12.2	6.6 a[‡]
Continuous	34.9	5.63 b
3 day	23.1	4.53 c
7 day	16.2	5.63 b
10 day	14.9	5.53 b

[†] VFTWRS = variable flow tailwater recovery system.

[‡] Means within a column followed by different letters are significantly different at *P* = 0.05 level. Tukey's honestly significant difference method was used for mean comparison.

Results from Three Years of the University of Arkansas System Division of Agriculture's Rice Irrigation Yield Contest

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Abstract

The University of Arkansas System Division of Agriculture's Irrigation Yield Contest was conducted in 2018, 2019, and 2020. The contest was designed to promote better use of irrigation water and to record data on water use and water use efficiency for various crops. Unlike yield contests, where winners are decided by yield alone, the irrigation contest results are decided by the highest calculated total water use efficiency (WUE) achieved by a producer. The contest consists of 3 categories: corn, rice, and soybeans. All fields entered were required to show a history of irrigation and production on the field. Irrigation water was recorded by using 8-in. and 10-in. portable mechanical flow meters. Rainfall totals were calculated using Farmlogs™. The contest average WUE of 2018–2020 for rice was 4.92 bu./in. The winning WUE was 8.72 bu./in. for 2020, 7.24 bu./in. for 2019, and 7.8 bu./in. for 2018. The adoption of irrigation water management practices such as computerized hole selection, surge irrigation, and soil moisture sensors is increasing. Rice contest participants report using on average 26.8 ac-in./ac of irrigation water, and 62% are using the furrow irrigation production system.

Introduction

According to data from 2015 reported by USGS, Arkansas ranks third in the United States for irrigation water use and second for groundwater use (Dieter et al., 2018). For comparison, Arkansas ranked 18th in 2017 in total crop production value (USDA-NASS, 2017). Of the groundwater used for irrigation, 96% comes from the Mississippi River Alluvial Aquifer (Kresse et al., 2014). One study of the aquifer found that 29% of the wells in the aquifer that were tested had dropped in water level between 2009 and 2019 (Arkansas Department of Agriculture Natural Resource Division, 2019).

Arkansas is the largest producer of rice in the U.S., producing 45.6% of the total rice in the U.S. (Hardke, 2019). The most common method of irrigation for rice is flood irrigation (Vories et al., 2002). Producers in Arkansas using flood irrigation use approximately 24–32 ac-in./ac of water (Henry et al., 2013). This equates to rice production using roughly half of all water taken from the Mississippi River Alluvial Aquifer in Arkansas (Kresse et al., 2014).

A study was conducted from 2013 to 2017 in primarily corn and soybean fields to assess the water-saving potential of implementing 3 irrigation water management (IWM) tools: computerized hole selection, surge irrigation, and soil moisture sensors (Spencer et al., 2019). Paired fields were set up with one using the IWM tools and one using conventional irrigation methods. It was found that the implementation of all 3 IWM tools reduced water use in the soybean fields by 21% while not reducing yields. This resulted in an increase in water use efficiency (WUE) of 36%. A 40% reduction in water use was observed for the cornfields, and WUE went up by 51%. For soybeans, when the cost of the new IWM tools was incorporated, no significant difference in net returns was found, but in corn, net returns were improved by adopting IWM.

The University of Arkansas System Division of Agriculture (UADA) Irrigation Yield Contest was designed as a novel way of encouraging the use of water-saving methods by Arkansas producers. The competition aimed to promote water-reducing management practices by educating producers on the benefits of irrigation water management tools, providing feedback to participants on how they compared to other producers, documenting the highest achievable water use efficiency in multiple crop types under irrigated production in Arkansas, and by recognizing producers who achieved a high WUE.

Procedures

Rules for an irrigation yield contest were developed in 2018. This contest was influenced by existing yield contests (Arkansas Soybean Association, 2014; National Corn Growers Association, 2015; National Wheat Foundation, 2018; University of California Cooperative Extension, 2018). The rules were designed to be as unobtrusive as possible to regular planting and harvesting operations. Fields must be at least 30 ac in size. A yield minimum of 180 bu./ac must be achieved to qualify.

A portable propeller-style mechanical flow meter was used to record water use. All flow meters were checked for proper installation and sealed using polypipe tape and serialized tamper-proof cables. Rainfall was recorded using Farmlogs™, an online software that provides rainfall data for a given location. Rainfall

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amounts were totaled from the date of emergence to the predicted drain date. Emergence was assumed as 7-d after the planting date provided on the entry form. To find the predicted drain date for the rice field, the UADA DD50 model was used (Hardke et al., 2020). Rainfall is adjusted for extreme events.

The harvest operations were observed by a third-party observer, often an Extension agent, NRCS employee, or UADA staff. A minimum of 3 acres was harvested from the contest field for the yield estimate.

The equation used for calculating WUE for the contest was: WUE = Y/(Pe + IRR), where WUE = water use efficiency in bushels per inch (bu./in.), Y = yield estimate from harvest in bushels per acre (bu./ac), Pe = Effective precipitation in inches (in.), and IRR = Irrigation application in ac-in./ac. Statistical analysis was performed using Microsoft Excel and JMP Pro 15 (SAS Institute, Inc., Cary, N.C.).

Results and Discussion

Detailed results are published on the contest website (www.uaex.edu/irrigation) for each year of the contest. Over the 3 years that the competition has been conducted, there have been 41 fields entered for rice. The average WUE over the 3 years was 4.92 bu./in. By year, the average WUE was: 4.69 bu./in. for 2020 with 21 contestants, 5.16 bu./in. for 2019 with 8 contestants, and 5.17 bu./in. for 2018 with 12 contestants (Table 1). The years 2018 and 2019 both had a higher average WUE than 2020. In 2020, there were more contestants in rice than in 2018 and 2019 combined. This may partially explain the lower WUE because more variation is expected with a larger number of growers. The winning WUE was higher in 2020 than in 2018 and 2019. The winning WUE for each year was: 8.72 bu./in. for 2020, 7.24 bu./in. for 2019, and 7.80 bu./in. for 2018.

It is a common belief that a higher or lower yield will help obtain a better WUE. By plotting WUE on one axis and yield on the other, a best fit line can be calculated. The line calculated has a coefficient of determination of $R^2 = 0.193$ where $R^2 > 0.95$ shows no relationship or correlation exists. There is no discernable relationship between yield and WUE in rice. Another commonly held belief by contestants is that a higher amount of rainfall will help to increase WUE. By plotting rainfall against WUE, linear regression was used to determine if there was a linear relationship. The coefficient of determination was determined to be $R^2 = 0.01$. There is no discernable relationship between WUE and precipitation. The lack of relationships suggests that neither precipitation nor yield is a factor in achieving high WUE and achieving high WUE is due to irrigation management.

In 2015, a survey was conducted across the Mid-South to determine the adoption rate of various IWM tools (Henry 2019). On the entry form for the contest, a similar survey was included to compare the usage of IWM tools among the participants in the contest to the average in use in the Mid-South and Arkansas. In the 2015 survey, 40% reported using computerized hole selection, and 66% of the Arkansas growers reported using computerized hole selection. 24% of respondents said they used soil moisture sensors in the region on their farm, and only 9% of Arkansas irrigators reported using soil moisture sensors.

Contestants are asked about their adoption of IWM tools when they enter the contest. In total, 64% of the participants across all 3 categories included responses in their entry form. The most widely adopted IWM tool was computerized hole selection. The average use among respondents was 89% across all three years, with 88% in 2018, 72% in 2019, and 100% in 2020. The use of furrow irrigated rice (FIR) increased during three years of the contest from 56% in 2018 and 50% in 2019 to 73% in 2020. Adding all years together, 62% of rice contest fields used furrow irrigation. Another water-saving method of rice irrigation is multiple inlet rice irrigation (MIRI). From all 3 years, 21% of respondents reported using MIRI, with 33% in 2018, 17% in 2019, and 27% in 2020. From all 3 years, 54% of respondents said that they used soil moisture sensors on their farm, with 60% in 2018, 67% in 2019, and 42% in 2020. Surge valves were the least used IWM tool, with 28% of respondents from all 3 years indicating that they used surge irrigation. This included 44% from 2018, 28% from 2019, and 16% from 2020.

Practical Applications

Irrigation water use efficiency (WUE) of working farms is not a standard metric available in the literature, and it is not a metric familiar to rice farmers. The data recorded from the UADA Irrigation Yield Contest provides direct feedback to irrigators about their irrigation performance in maintaining high yields and low irrigation water use. Such feedback to Arkansas rice farmers will likely provide many with a competitive advantage when water resources become scarcer. It provides a mechanism for rice farmers to evaluate the potential for water savings by adopting water-saving techniques or management changes.

On average, rice growers in the contest across the 3 years averaged 26.8 ac-in./ac and a total water use of 43 in. of total water for rice.

Acknowledgments

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Table 1. Maximum, average, and minimum for 2018, 2019, and 2020 of various water and yield data points for rice from the Arkansas Irrigation Yield Contest.

Year	Max., Average, and Min.	Water Use Efficiency	Yield	Adjusted Rainfall	Irrigation Water	Total Water
		(bu./in.)	(bu./ac)	(in.)	(ac-in./ac)	(in.)
2020	**Maximum**	8.72	250	18.1	92.1	104.2
	Average	4.69	196.4	14.9	32.4	47.4
	Minimum	1.55	120.0	11.7	14.0	27.6
2019	**Maximum**	7.24	209.9	27.1	30.5	48.7
	Average	5.20	189.6	19.2	19.9	39.2
	Minimum	3.55	162.8	14.9	13.4	28.7
2018	**Maximum**	7.80	266.6	16.0	47.9	63.8
	Average	5.20	208.9	13.7	28.1	42.5
	Minimum	2.84	131.9	7.4	16.0	29.4
3 Yr.	**Average**	4.92	199.0	15.4	28.7	44.3

Influence of Rice Row Spacing and Seeding Rate on Stand Density and Grain Yield

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Abstract

Arkansas rice (*Oryza sativa* L.) producers implementing a direct-seeded, delayed flood practice have primarily planted using 7.5-in. row spacings. During the summer of 2020, a field experiment was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas, and at the Northeast Research and Extension Center (NEREC) near Keiser, Arkansas, to evaluate different drill row spacings and seeding rates. The 2 cultivars evaluated were Diamond, a pure-line variety, and RT XP753, a hybrid. Drill row spacings evaluated were 3.25, 7.5, and 15 in. Seeding rates for Diamond included 10, 20, and 30 seeds/ft^2 and 4, 7, 10, 13, and 16 seeds/ft^2 for RT XP753. In Diamond at the RREC and at the NEREC, the 3.25-in. and 7.5-in. row spacings had significantly higher grain yields than the 15-in. row spacing. For RT XP753 at the RREC, the 3.25-in. row spacing yielded significantly higher than the two wider spacings, with the 7.5-in. spacing also yielding higher than the 15-in. spacing. At the NEREC in RT XP753, the 3.25-in. and 7.5-in. row spacings resulted in significantly higher yields than the 15-in. spacing. Seeding rates resulted in a linear trend regarding stand density.

Introduction

In Arkansas, the most common rice (*Oryza sativa* L.) planting practice is dry, drill seeding, or direct seeding. Current University of Arkansas System Division of Agriculture (UADA) rice drill row spacing recommendations include a range of 4- to 10-in. spacings, but 7.5-in. drill rows have been the most widely used by producers. From previous work conducted in 2004 and 2005, it was shown that narrower 7-in. row spacings resulted in higher rice grain yields than wider 10-in. row spacings (Frizzell et al., 2006). For conventional varieties, the optimal plant stand is from 10–20 plants/ft^2 and 6–10 plants/ft^2 for hybrid cultivars. Seeding rates of about 30 seed/ft^2 for conventional varieties and 10 seed/ft^2 are recommended to achieve these desired stands. There are also other factors that may contribute to an adjustment of dry, drilled seeding rate (Hardke et al., 2018).

Procedures

An experiment was initiated to determine the effect of row spacing and seeding rate on rice grain yield and stand density for direct-seeded, delayed flood rice in Arkansas. The field experiment was conducted during the summer of 2020 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) in Stuttgart, Arkansas, on a DeWitt silt loam soil and at the Northeast Research and Extension Center (NEREC) in Keiser, Arkansas on a Sharkey clay soil. The experiment was set up as a 2-factor factorial randomized complete block design, with the first factor being row spacing and the second factor being seeding rate with 4 replications. The treatments included 3.25, 7.5, and 15-in. row spacings as well as seeding rates of 10, 20, and 30 seed/ft^2 for Diamond, and 4, 7, 10, 13, and 16 seed/ft^2 for RT XP753. An 8-row Almaco© grain drill was used to plant 16.5-ft long plots. Seed tubes were manipulated in order to achieve 3.25-in. and 15-in. row spacings. Three to 4 weeks after rice emergence, stand density was determined by counting the number of emerged seedlings in 10 row-feet. A single preflood nitrogen (N) application was made at each location using the rates of 130 lb N/ac at RREC and 160 lb N/ac at NEREC. The center 30 in. of each plot were harvested at maturity, and grain weight and moisture content were determined. Grain yields were reported on a bushel per acre (bu./ac) basis, and moisture was adjusted to 12%. The data were analyzed using analysis of variance, PROC GLIMMIX, through SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) and a 10% level of significance.

Results and Discussion

In 2020 for Diamond at both the RREC and NEREC, the 3.25-in. and 7.5-in. spacings resulted in significantly higher grain yields compared to the 15-in. spacing (Table 1). For RT XP753 at both RREC and NEREC, the 3.25-in. and 7.5-in. row spacings had significantly higher yields than the 15-in. spacing. In addition, at RREC, RT XP753 at 3.25-in. spacing produced significantly higher yields than the 7.5-in. spacing.

For Diamond at RREC and NEREC, the 3.25-in. spacing resulted in the highest plant stand densities (Table 2). At RREC, the 3.25-in. and 7.5-in. spacings had higher stand densities than the 15-in. spacing, while at NEREC, the 3.25-in. spacing had higher stand densities than both the 7.5-in. and 15-in. spacings. For RT XP753 at both RREC and NEREC, the 3.25-in. spacing had significantly greater stand densities than both the 7.5-in. and

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15-in. spacings, while the 7.5-in. spacing also had higher stand densities than the 15-in. spacing.

When evaluating Diamond seeding rates averaged across drill row spacings, the 30 seed/ft^2 seeding rate resulted in significantly higher rice grain yields than the 10 seed/ft^2 seeding rate at the RREC and as the seeding rate increased from 10–30 seed/ft^2, the stand density subsequently increased (Table 3). For Diamond at the NEREC, the 20 and 30 seed/ft^2 seeding rates resulted in rice grain yields significantly greater than the 10 seed/ft^2 seeding rate. Stand density resulted in a linear increase with an increasing seeding rate at the NEREC for Diamond.

For RT XP753 at the RREC, the 13 and 16 seed/ft^2 resulted in rice grain yields significantly greater than the 4 and 7 seed/ft^2 rates but were not significantly higher than the 10 seed/ft^2 rate. While there were significant differences, stand density increased in a linear fashion according to the seeding rate. At the NEREC for RT XP753, there was no significant grain yield difference observed among seeding rates. Stand density was linear with increasing seeding rate.

Practical Applications

The rice grain yields produced in this study using a 3.25-in. row spacing indicate a need to further evaluate this rice row spacing. The 3.25-in. spacing produced yields similar to or greater than other drill row spacings evaluated. In future studies, additional drill row spacings will need to be assessed. The Diamond seeding rate results were consistent with previous studies that suggest 30 seed/ft^2 is needed to maximize yield, but there may be the opportunity to slightly reduce the seeding rate under certain conditions. For the RT XP753 seeding rate, results were also consistent with previous research that suggests 10 seed/ft^2 can maximize grain yield, but lower seeding rates may perform similarly under certain conditions. Further row spacing × seeding rate studies evaluating rice grain yield and stand density are necessary and will be conducted in the future.

Acknowledgments

The authors wish to thank all Arkansas rice producers for financial support through the Arkansas Rice Checkoff Program administered by the Arkansas Rice Research and Promotion Board as well as the University of Arkansas System Division of Agriculture.

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Table 1. Effect of row spacing averaged across seeding rates on rice grain yield during 2020.

	Grain yield			
	Diamond		RT XP753	
Row spacing	**RREC**†	**NEREC**	**RREC**	**NEREC**
(in.)	(bu./ac)			
3.25	220 a‡	137 a	256 a	195 a
7.5	218 a	139 a	249 b	198 a
15	194 b	116 b	238 c	181 b
P-value	<0.0001	<0.0001	0.0002	0.0215

† RREC = Rice Research and Extension Center; NEREC = Northeast Research and Extension Center.

‡ Means within a column followed by the same letter are not significantly different at P = 0.10.

Table 2. Effect of row spacing averaged across seeding rates on rice stand density during 2020.

	Stand density			
	Diamond		RT XP753	
Row spacing	**RREC[†]**	**NEREC**	**RREC**	**NEREC**
(in.)	---(E.S.[§]/10 row ft)---			
3.25	12.5 a	21.0 a	9.0 a	11.0 a
7.5	11.1 a	12.8 b	6.4 b	6.4 b
15	8.9 b	12.0 b	5.5 c	5.5 c
P-value	0.0078	<0.0001	<0.0001	<0.0001

[†] RREC = Rice Research and Extension Center; NEREC = Northeast Research and Extension Center.
[‡] Means within a column followed by the same letter are not significantly different at $P = 0.10$.
[§] E.S. = Emerged seedlings.

Table 3. Effect of Diamond at 3 seeding rates averaged across row spacing on stand density and rice grain yield during 2020.

	Diamond			
	RREC[†]		NEREC	
Seeding rate	**Grain yield**	**Stand density**	**Grain yield**	**Stand density**
(seeds/ft²)	**(bu./ac)**	**(E.S.[‡]/10 row ft)**	**(bu./ac)**	**(E.S./10 row ft)**
10	204 b[§]	6 c	122 b	9 c
20	211 ab	12 b	135 a	16 b
30	215 a	17 a	135 a	21 a
P-value	0.0700	<0.0001	0.0060	<0.0001

[†] RREC = Rice Research and Extension Center; NEREC = Northeast Research and Extension Center.
[‡] E.S. = Emerged seedlings.
[§] Means within a column followed by the same letter are not significantly different at $P = 0.10$.

Table 4. Effect of RT XP753 at 5 seeding rates averaged across row spacing on stand density and rice grain yield during 2020.

	RT XP753			
	RREC[†]		NEREC	
Seeding rate	**Grain yield**	**Stand density**	**Grain yield**	**Stand density**
(seeds/ft²)	**(bu./ac)**	**(E.S.[‡]/10 row ft)**	**(bu./ac)**	**(E.S./10 row ft)**
4	239 c[§]	3 d	186 a	4 e
7	241 bc	6 c	193 a	6 d
10	249 ab	7 b	186 a	8 c
13	252 a	9 b	198 a	10 b
16	257 a	13 a	194 a	13 a
P-value	0.0031	<0.0001	0.4711	<0.0001

[†] RREC = Rice Research and Extension Center; NEREC = Northeast Research and Extension Center.
[‡] E.S. = Emerged seedlings.
[§] Means within a column followed by the same letter are not significantly different at $P = 0.10$.

Rice Grain Yield as Influenced by Planting Arrangement and Seeding Rate

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Abstract

Rice (*Oryza sativa* L.) production in Arkansas is primarily a direct-seeded, delayed flood practice. Planting in corn (*Zea mays* L.), another grass crop, has become optimized where seed spacing is equidistant and precise. This ability is a major component in corn production to be able to achieve full yield potential. In 2020, a field experiment was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas, on a DeWitt silt loam soil and at the Northeast Research and Extension Center (NEREC) near Keiser, Arkansas on a Sharkey clay soil. The experiment was set up as a 2-factor factorial randomized complete block design. The first factor was planting arrangement, and the second factor was seeding rate. The study consisted of 2 cultivars, Diamond, a conventional variety, and a hybrid cultivar, RT XP753. Diamond was planted at the seeding rates of 10, 20, 30, 40, and 50 seed/ft^2, and RT XP753 was planted at the seeding rates of 4, 7, 10, 13, and 16 seed/ft^2. The seed was planted in either a single (straight) pass or 2 perpendicular (crossed) passes using a grain drill with 7.5-in. spaced row units. The crossed planting arrangement resulted in significantly higher yields for Diamond at NEREC and RT XP753 at both RREC and NEREC when averaged across seeding rates.

Introduction

Arkansas rice (*Oryza sativa* L.) producers currently do not possess the ability to precision plant rice, as corn (*Zea mays* L.), another grass crop, producers are able to do. Because of the ability to plant corn uniformly and equidistantly, producers are better able to achieve full yield potential. Because direct-seeded rice is planted in rows, when seeding rates or row spacings are manipulated then interplant competition fluctuates greatly (Jones and Snyder, 1987). Optimizing plant spatial density may result in other yield-protecting benefits as well, such as weed control. Current University of Arkansas System Division of Agriculture recommendations include drill row widths from 4–10 in., but 7.5-in. is the most commonly employed spacing by producers. The desired plant stands for conventional varieties range from 10–20 plants/ft^2. Under optimal conditions, 30 seed/ft^2 are necessary to achieve that preferred stand. When planting a hybrid cultivar, seeding rates of 10–15 seed/ft^2 are required to achieve stands of 6–10 plants/ft^2 (Hardke et al., 2018).

Procedures

In 2020, a field study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Arkansas, on a DeWitt silt loam soil, and at the Northeast Research and Extension Center (NEREC) near Keiser, Arkansas on a Sharkey clay soil. The experiment was set up as a 2-factor factorial randomized complete block design. The first factor was planting arrangement and the second factor was seeding rate. The first planting arrangement treatment was a single pass in 1 direction (straight). The second planting arrangement treatment was comprised of 2 passes, 1 initial pass and then a second pass that is perpendicular to the first (crossed). A drill row spacing of 7.5-in. was used for all treatments.

Two cultivars were planted, Diamond, a conventional variety, and RT XP753, a hybrid. Using an 8-row Almaco© (Almaco, Nevada, IA) drill, Diamond was planted at the seeding rates of 10, 20, 30, 40, and 50 seed/ft^2. The cultivar RT XP753 was planted at 4, 7, 10, 13, and 16 seed/ft^2. The plot dimensions were 16.5-ft long by 5-ft wide. When the rice reached the 3–4 leaf growth stage, stand counts were taken by counting the number of emerged rice seedlings within 1 ft^2 at 3 random locations within the plot. At the V5 growth stage, a single preflood nitrogen (N) application was made of 130 lb N/ac at the RREC and 160 lb N/ac at the NEREC. The 4 center rows will be harvested at rice maturity, and the grain yield will be expressed on a bushel per acre (bu./ac) basis. Moisture was adjusted to 12%. The data were analyzed using analysis of variance with JMP Pro 14 (SAS Institute, Inc., Cary, N.C.) and a 10% level of significance.

Results and Discussion

There were no planting arrangement × seeding rate interactions observed, only main effects. At the RREC for Diamond, there were no significant grain yield differences observed between the straight planting arrangement and the crossed planting arrangement (Table 1). There were also no significant grain yield differences between seeding rates in Diamond at the RREC (Fig.

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1). For RT XP753 at the RREC, the crossed planting arrangement resulted in significantly higher rice grain yields than the straight planted passes. The 7, 13, and 16 seed/ft^2 seeding rates resulted in significantly higher grain yields than the 4 seed/ft^2, but not the 10 seed/ft^2 seeding rate at the RREC in RT XP753 (Fig. 2).

For Diamond at the NEREC, the crossed planting arrangement resulted in significantly higher rice grain yields than the straight planted passes (Table 1). The 40 and 50 seed/ft^2 seeding rates had similar grain yields, but the 40 seed/ft^2 seeding rate did result in significantly higher rice grain yields than the 10, 20, and 30 seed/ft^2 seeding rates (Fig. 1). For RT XP753 at the NEREC, the crossed planting arrangement resulted in significantly higher rice grain yields than the straight planted passes (Table 1). The 10 and 16 seed/ft^2 seeding rates resulted in the highest grain yields but were not significantly higher than the 13 seed/ft^2 seeding rate (Fig. 2).

Practical Applications

The 2020 planting arrangement study suggests that a crossed planting arrangement may result in increased grain yields compared to traditional single-direction planting arrangements. In general, the response to seeding rate was similar for both crossed and straight planted arrangements. Additional research is needed to determine if lower seeding rates can be utilized with a crossed planting arrangement to decrease the cost of the additional planting pass. Further analysis is also needed to determine if the increase in yield justifies the time and cost associated with an additional planting pass.

Acknowledgments

The authors wish to thank all Arkansas rice producers for financial support through the Arkansas Rice Checkoff Program administered by the Arkansas Rice Research and Promotion Board as well as the University of Arkansas System Division of Agriculture.

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Table 1. Influence of planting arrangement on rice grain yield at two locations in two cultivars during 2020.

	Diamond		RT XP753	
Arrangement	**RREC**[†]	**NEREC**	**RREC**	**NEREC**
	----------	----------(bu./ac)	----------	----------
Straight	231 a[‡]	145 b	248 b	210 b
Crossed	236 a	165 a	256 a	234 a
P-value	0.4078	< 0.0001	0.0256	<0.0001

[†] RREC = Rice Research and Extension Center; NEREC = Northeast Research and Extension Center

[‡] Means within a column followed by the same letter are not significantly different at P = 0.10.

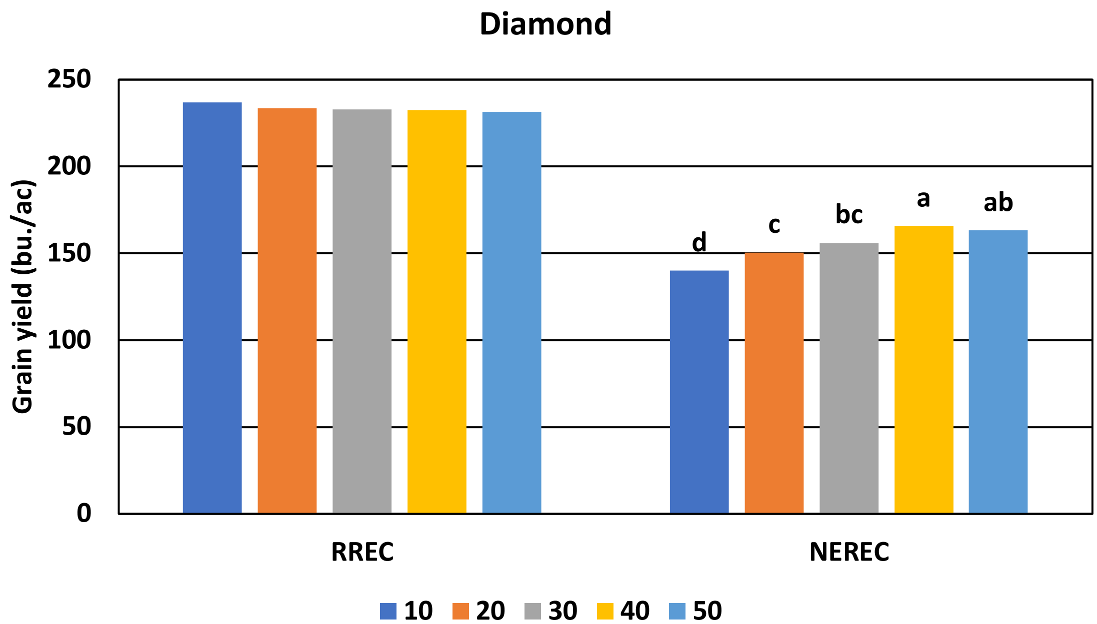

Fig. 1. Influence of Diamond at 5 seeding rates (seed/ft^2) on rice grain yield at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) and at the Northeast Research and Extension Center (NEREC) during 2020. Treatments with the same lowercase letter are not significantly different according to Fisher's protected least significant difference at α = 0.10.

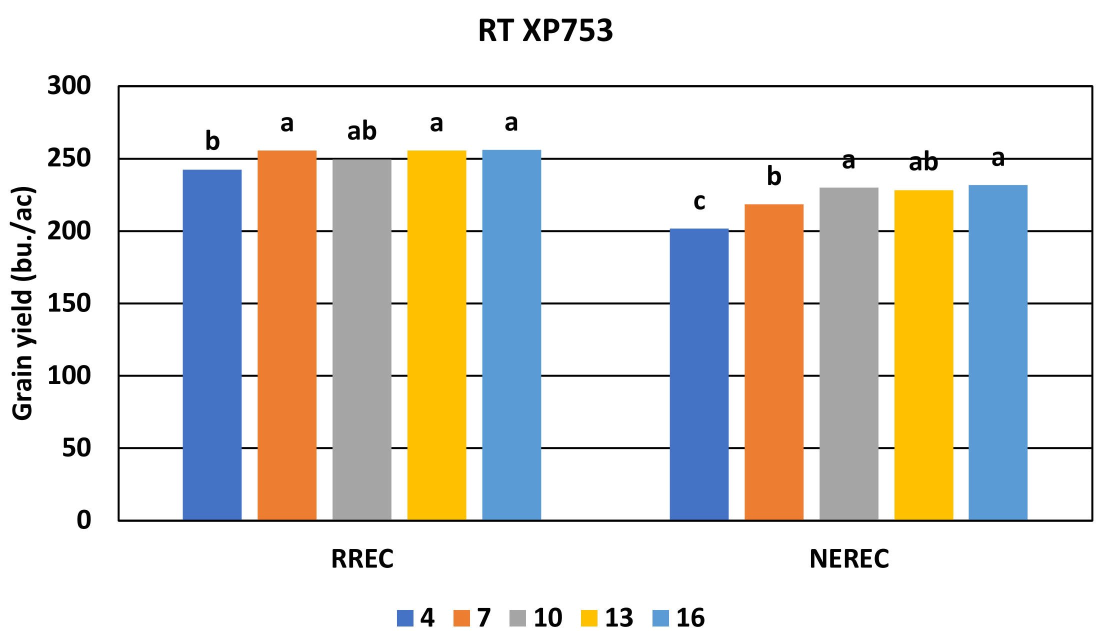

Fig. 2. Influence of RT XP753 at 5 seeding rates (seed/ft^2) on rice grain yield at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) and at the Northeast Research and Extension Center (NEREC) during 2020. Treatments with the same lowercase letter are not significantly different according to Fisher's protected least significant difference at α = 0.10.

Summary of Nitrogen Soil Test for Rice (N-STaR) Nitrogen Recommendations in Arkansas During 2020

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Abstract

Seeking to fine-tune nitrogen (N) application, increase economic returns, and decrease environmental N loss, some Arkansas rice (*Oryza sativa* L.) producers are turning away from blanket N recommendations based on soil texture and cultivar and using N-STaR (Nitrogen Soil Test for Rice) to determine their field-specific N rates. In 2010, Roberts et al. correlated several years of direct steam distillation (DSD) results obtained from 0 to 18-in. soil samples to plot-scale N response trials across the state to develop a field-specific, soil-based N test for Arkansas rice. After extensive small-plot and field-scale validation, N-STaR is available to Arkansas farmers for both silt loam and clay soils (using 0 to 12-in. soil samples). To summarize the samples submitted to the N-STaR Soil Testing Lab in 2020, samples were categorized by county and soil texture. Samples were received from 24 fields across 11 Arkansas counties. Total samples received were from 9 clay and 15 silt loam fields. Sample submission was depressed this season due to COVID-19, but expectations are that sample numbers will increase for the 2021 growing season. The N-STaR N-rate recommendations for these samples were compared to the producer's estimated N rate, the 2020 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas, and the standard Arkansas N-rate recommendation of 150 lb N/ac for silt loam soils and 180 lb N/ac for clay soils. Each comparison was divided into 3 categories based on a decrease in the recommendation, no change in recommended N rate, or an increase in the N rate recommendation. Neither county nor soil texture was found to be significant factors in any of the comparisons made in this year's data, yet the same general trends seen in previous years were observed.

Introduction

Nitrogen (N) recommendations for rice in Arkansas were historically based on soil texture, cultivar selection, and the previous crop—often resulting in over-fertilization which can decrease possible economic returns and increase environmental N loss (Khan et al., 2001). In the quest for a field-based factor to drive N recommendations, scientists correlated several years of plant available-N estimates from direct steam distillation (DSD) results from 0 to 18-in. soil samples, equivalent to rice rooting depth on a silt loam soil (Roberts et al., 2009) to plot-scale N response trials across the state and developed a site-specific, soil-based N test for Arkansas rice (Roberts et al., 2011). Direct-seeded, delayed-flood rice production, with proper flood management, the use of ammonium-based fertilizers, and best management practices, has a consistent N mineralization rate and one of the highest N use efficiencies of any cropping system; therefore, it lends itself to a high correlation of mineralizable-N to yield response (Roberts et al., 2011). After extensive field-testing and validation, N-STaR became available to the public for silt loam soils in 2012 with the initiation of the University of Arkansas System Division of Agriculture's N-STaR Soil Testing Lab in Fayetteville. Later, researchers correlated direct steam distillation results from 0 to 12-in. soil samples to N response trials on clay soils (Fulford et al., 2019), and N-STaR rate recommendations became available for clay soils in 2013. Some Arkansas farmers are benefiting from this research by using N-STaR's field-specific N rates, but many continue to depend on soil texture, cultivar, or routine management habits to guide N-rate decisions, which may not always be the most profitable or environmentally sound practice.

Procedures

To evaluate the effect of the N-STaR program in Arkansas, samples submitted to the N-STaR Soil Testing Lab for the 2020 growing season were categorized by county and soil texture. The N-STaR rate recommendations for these samples were then compared to the producer's estimated N rate supplied on the N-STaR Soil Test Laboratory Soil Sample Information Sheet, the 2020 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas found in the 2020 Rice Management Guide (Hardke et al., 2020), or to the standard Arkansas N-rate recommendation of 150 lb N/ac for silt loam soils and 180 lb N/ac for clay soils. Results were then divided into 3 categories—those with a decrease in N fertilizer rate recommendation, no change in recommended N rate, or an increase in the N rate recommendation. The resulting data were analyzed using JMP 15 (SAS Institute, Inc., Cary, N.C.) with means separated using Fisher's least significant difference test ($P = 0.05$).

Results and Discussion

Samples were submitted from 24 producer fields across 11 Arkansas counties during the 2020 production year, a stark con-

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trast to the 304 fields sampled in 2013 when the program was initiated and costs were partially subsidized. Lonoke County ranked third in planted acres, and Randolph County ranked nineteenth (USDA-FSA, 2020), each submitted samples from 6 fields, the largest number of fields from an individual county. All samples from Randolph County and half of those from Lonoke County were submitted by producers. Samples from 10 of the 24 total fields, including the remaining half of the Lonoke County samples, were submitted by local Agriculture Extension Agents to represent Rice Research Verification fields and other demonstration projects across the state. The average number of fields submitted by client was 1.8, with only 4 clients submitting samples from more than a single field. Seventy-five percent of the 2020 samples were received after rice had been planted during the typically wetter spring months when soil sampling at proper moisture is more problematic than the 25% that were submitted after harvest of the previous crop. The samples received were from 15 silt loam fields and 9 clay fields (Table 1).

Much like 2019, 2020 gave farmers a wet spring that delayed rice planting progress until later in the year. However, rains and cooler temperatures did finally break, allowing Arkansas planted rice acreage to increase in 2020 from the 1.15 million acres planted in 2019 to 1.44 million acres, mirroring the rice acreage of 2018 (USDA-FSA, 2020). However, another wet spring coupled with the rush to get rice planted and favorable N prices likely decreased the number of samples that would have been submitted for N-STaR analysis. Additionally, the COVID-19 pandemic and the uncertain times led many producers to not take samples. Just as in previous years, sample submission by county in 2020 (Fig. 1) did not reflect the planted acre estimates with no samples received from Poinsett County, which had the highest planted acreage estimates (USDA-FSA, 2020).

When the N-STaR recommendations were compared to Arkansas' standard N-rate recommendation of 150 lb N/ac for silt loam soils and 180 lb N/ac for clay soils, neither county nor soil texture was found to be a significant factor. However, the same general trends present in previous years can be seen (Fig. 1) where more counties, twice as many, saw decreased N rates when compared to N-STaR, suggesting that some areas of the state may be prone to N savings potential due to cropping systems and higher native soil-N levels. There were no increases in N rate among the clay-textured soils submitted (Table 1). It should be noted that the validation of N-STaR on clay soils found no increased yield response to fertilizer rates above the standard N recommendation; therefore, N-STaR does not recommend N rates greater than 180 lb N/ac (Davidson et al., 2016). Of the fields in this comparison, there was a decrease in the N recommendation for 15 fields (63% of the 24 fields submitted) with an average decrease of 40.7 lb N/ac. No change in N recommendation was found for 2 fields, while 7 silt loam fields had an increase in N recommendation (29%), with an average increase of 10.7 lb N/ac. The N-STaR recommendations continue to be largely dependent on proper sampling depth for the respective soil texture and the correct soil textural classification of the field.

Three of the submitted fields had no estimated N rate specified on the N-STaR Sample Submission Sheet and were excluded from the comparison of the N-STaR recommendation to the producer's estimated N rate. Of the 21 fields that were compared, there was a decrease in N recommendations for 13 fields (54% of the compared fields) with an average decrease of 32.3 lb N/ac (Table 2). No change in N recommendation was found for 2 fields, while 7 fields had an increase in N recommendation (29%), with an average increase of 14.3 lb N/ac. Five clay fields listed their producer's estimated N rate as only 150 lb N/ac. Again, neither county nor soil texture were significant factors in this comparison.

When the N-STaR recommendation was compared to the 2020 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas, cultivar recommendations were adjusted for soil texture as recommended by adding 30 lb N/ac for rice grown on clay soils and then compared to the N rates determined by N-STaR. Two fields failed to include cultivar on the N-STaR Sample Submission Sheet and were excluded from this comparison. There was a decrease in the N recommendation for 13 fields (54% of the 22 fields) with an average decrease of 36.2 lb N/ac (Table 3). No change in N recommendation was found for 2 fields (9%), while 7 silt loam fields had an increase in N recommendation (29%), with an average increase of 10.7 lb N/ac. No significant differences were found in either county or soil texture in this comparison.

In all 3 comparisons, N-STaR proposed decreases as high as 75 lb N/ac in some fields. Decreases greater than 30 lb N/ac were proposed in 50%, 43%, and 41% of fields evaluated in the standard, estimated, and cultivar rate comparisons, respectively. Alternatively, the greatest N-STaR recommended-N rate increase in all comparisons was only 15 lb N/ac, except for 1 clay field, wrongly classified as a silt loam, where the increase from the estimated N rate was the routine additional 30 lb N/ac.

Practical Applications

Despite decreased submission numbers, these results continue to show the value of the N-STaR program to Arkansas producers and can help target areas of the state that would most likely benefit from its incorporation. Standard recommendations and cultivar recommendations will continue to be good starting points for N recommendations, but field-specific N rates continue to offer the best estimate of needed N, regardless of soil texture or cultivar selection. By using a field-specific N rate, farmers could save a large fraction of fertilizer costs as fertilizer-N costs rise in the future as well as decrease possible negative environmental impacts as concerns intensify to protect the sensitive Mississippi watershed. Farmers are encouraged to consider taking N-STaR samples at the harvest of the previous crop when fields are typically in optimal conditions for soil sampling.

Acknowledgments

This research was funded by Arkansas Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board and the University of Arkansas Division of Agriculture. Sincere gratitude is extended to the employees of the University of Arkansas N-STaR Soil Testing Lab and the hourly personnel who spent many hours conducting the analysis of N-STaR samples.

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Table 1. Distribution and change in nitrogen (N) fertilizer rate compared to the standard recommendation, producer's estimated N rate, and the 2020 recommended nitrogen rates and distribution for rice cultivars in Arkansas based on soil texture.[a]

Soil Texture	Number of Fields Submitted	Decreased N-STaR Recommendation		Increased N-STaR Recommendation		No Change in Recommendation
		Number of Fields	Mean N Decrease	Number of Fields	Mean N Increase	
			(lb N/ac)		(lb N/ac)	
Standard soil texture						
Clay	9	7	41.4	-	-	2
Silt Loam	15	8	40.0	7	10.7	-
Total	24	15	40.7	7	10.7	2
Producer estimate						
Clay	8	5	23.0	3	20.0	-
Silt Loam	13	8	38.1	4	10.0	1
Total	21	13	32.3	7	14.3	1
Cultivar						
Clay	7	5	36.0	-	-	2
Silt Loam	15	8	36.3	7	10.7	-
Total	22	13	36.2	7	10.7	2

[a] Failure to include a producer's estimated N rate excluded 3 fields from the producer's estimate comparison, while failure to list cultivar excluded 2 fields from the cultivar comparison.

Table 2. Distribution and change in nitrogen (N) rate compared to the producer's estimated N rate by county.[a]

County	Number of Fields Submitted	Decreased N-STaR Recommendation: Number of Fields	Decreased N-STaR Recommendation: Mean N Decrease	Increased N-STaR Recommendation: Number of Fields	Increased N-STaR Recommendation: Mean N Increase	No Change in Recommendation
			(lb N/ac)		(lb N/ac)	
Clay	1	-	-	1	15	-
Crittenden	1	1	35.0	-	-	-
Drew	1	1	5.0	-	-	-
Lawrence	4	3	30.0	1	15.0	-
Lonoke	6	3	51.7	3	16.7	-
Mississippi	1	1	20.0	-	-	-
Monroe	1	1	30.0	-	-	-
Randolph	5	3	28.3	1	5.0	1
Woodruff	1	-	-	1	15.0	-
Total	21	13	32.3	7	14.3	1

[a] Three fields were excluded from this analysis because no estimated N rate was listed on the sample submission sheet.

Table 3. Distribution and change in nitrogen (N) rate compared to the 2020 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas by cultivar.[a]

Cultivar	Number of Fields Submitted	Decreased N-STaR Recommendation: Number of Fields	Decreased N-STaR Recommendation: Mean N Decrease	Increased N-STaR Recommendation: Number of Fields	Increased N-STaR Recommendation: Mean N Increase	No Change in Recommendation
			(lb N/ac)		(lb N/ac)	
CL151	1	1	5.0	-	-	-
Diamond	6	5	41.0	1	15.0	-
Jupiter	6	2	30.0	4	10.0	-
RT Gemini 214 CL	4	2	32.5	1	15.0	1
RT XP753	5	3	45.0	1	5.0	1
Total	22	13	36.2	7	10.7	2

[a] Two fields did not list a cultivar on their N-STaR Sample Submission Sheet and were excluded from the analysis.

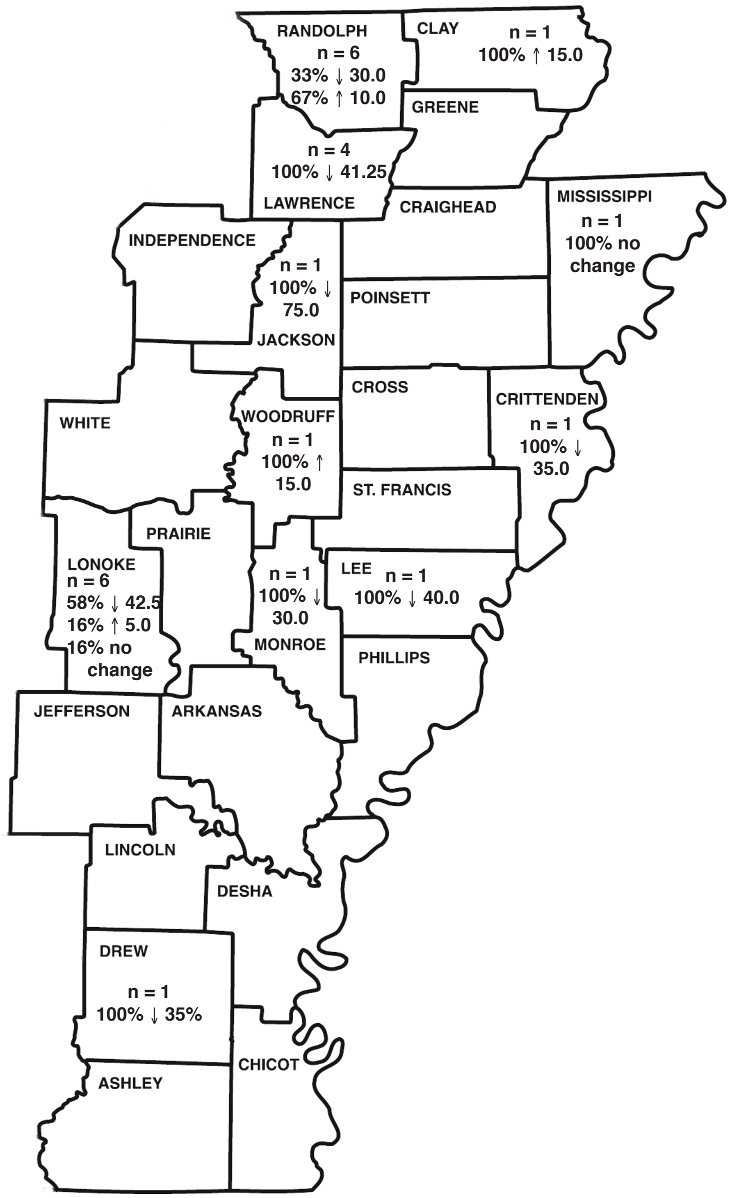

Fig. 1. Number of fields submitted, percent, and mean decrease and increase in N-STaR nitrogen (N) recommendation (lb N/ac) by county compared to the standard recommendation.

Effects of Infrared Heat Treatment on the Pasting Properties of Long-Grain Rice

G.G. Atungulu[1] *and A.A. Oduola*[1]

Abstract

Rapid drying of rice to a safe moisture content (MC) is an important step during rice processing. Infrared (IR) heat treatment has been observed to result in rapid drying and decontamination of rice. However, IR heat has a high energy transfer rate and may have impacts on rice quality. The objective of this study was to investigate the effect of using selected IR wavelength to treat rice and investigate the treatment impacts on rice pasting properties. Long-grain, hybrid rough rice (RT XP753) at a MC of 18.4% wet basis (w.b.) was used for this study. A 0.44-lb sample was subjected to each treatment combination. The samples were treated using 9 IR intensities (ranging from 83.06 to 3.86 BTU/min ft^2), 3 product-to-emitter distances (4.33, 10.83, and 17.32 in.), and 3 heating durations (10, 20, and 30 s). The MCs of the treated samples were conditioned to 12.5% w.b. before milling. The milled rice samples were ground, and the pasting properties were determined. Rice treated with an IR intensity of 83.06 BTU/min ft^2 for 30 s resulted in a significant reduction of peak viscosity from 2511.67 to 1997.33 centipoise (cP). The final viscosity of rice treated at IR intensity of 83.06 BTU/min ft^2 for 30 s was reduced from 2902 to 2592.5 cP. Breakdown, trough, and setback viscosities of rice treated at IR intensity of 83.06 BTU/min ft^2 were also significantly reduced ($P < 0.05$).

Introduction

It is important to rapidly dry freshly harvested rice of high moisture content (MC) to a safe MC of 12–14% wet basis (w.b.) to prevent rice quality degradation. Infrared (IR) heat technique has shown great promise in simultaneously drying and inactivating microbial contaminants on grains, including rice (Oduola et al., 2020; Wilson et al., 2017). Furthermore, IR heat has a high energy transfer rate, mild impact on the environment, and positive impact on the milling quality of rice (Khir et al., 2011; Wang et al., 2014). In this study, a ceramic emitter powered by electricity was used to generate 3 different IR wavelengths (126, 177.2, and 228.3 microinches (µin)). Since the IR heat technique supplies a high-heat flux to the surface of the grain, it may have effects on the rice quality, including pasting properties.

The temperatures at which rice is dried may have an effect on rice pasting properties (Bruce et al., 2020; Fan et al., 2019). High temperature may cause starch gelatinization and starch granules disintegration (Fan et al., 2019; Jamradloedluk et al., 2007). Also, the swelling and retrogradation of starch granules in rice may be affected by high temperatures (Zhou et al., 2003). Cheevisopon and Noomhorm (2011) reported that a drying temperature of 302 °F for 6 mins using a fluidized bed dryer had a significant effect on the cooking quality and physicochemical properties of rice. To the best of our knowledge, there is no information on the effect of different IR wavelengths on the pasting properties of rice.

The objective of this study was to investigate the effect of using selected IR wavelength treatment on the pasting properties of rice.

Procedures

Sample Preparation. Long-grain, hybrid rough rice (RT XP753) with initial moisture content (MC) of 18.4% wet basis (w.b.) was obtained from Poinsett Rice Inc., Waldenburg, Arkansas, and used in this study. The sample was cleaned and stored in a walk-in refrigerator at 39.2 °F.

Selected Infrared Wavelength Equipment: A lab-scale IR equipment that generates different IR wavelengths (Tempco Electric Heater Corporation, Ill.) was used in this study. This equipment was previously described by Oduola et al. (2020).

Selected Infrared Wavelength Treatment: For each treatment, 0.44 lb of rough rice was weighed onto a flat rectangular pan. The sample was spread out to form a single layer. The tray was then put in the product-holding bed of the IR equipment. The tray was placed at 3 product-to-emitter distances (distance between the emitters and sample) of 4.33, 10.83, and 17.32 in. for 3 different heating durations (10, 20, and 30 s). Three peak wavelengths (126, 177.2, and 228.3 µin.) were used for the treatment. A combination of a product-to-emitter distance and a wavelength gives a specific IR intensity shown in Table 1. After IR heat treatment, the samples were allowed to cool to 77 °F before storing them in sterile bags for further analysis. Control samples received no IR heat treatment. All treatments were done in triplicate.

Rice Milling: After the IR heat treatment, the samples were gently dried to 12.5% MC w.b. in an equilibrium moisture chamber (EMC) set at 77 °F and 65% relative humidity. Afterward, a laboratory huller (Satake rice machine, Satake Engineering, Tokyo, Japan) was used to dehull the rough rice. Dehulled rice was milled for 30 s (to obtain surface lipid content standardized at 0.4%) using a lab-scale mill (McGill number 2 rice mill, Rapsco, Brookshire, Texas). Milled rice was put in a seed blower for 2 min (South Dakota seed blower, Seedboro, Chicago, Ill.) to remove the dust and other small particles. Head rice was separated from broken kernels using a double-tray sizing machine (Grainman Machinery Manufacturing Corp., Miami, Fla.). Head rice is re-

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ferred to as kernels that remained whole or at least three-fourths of the original kernel length after milling (Siebenmorgen, 2014). Head rice was used in determining the pasting properties of rice.

Pasting Properties Determination: The pasting properties of rice flour viscosity were determined according to the AACC international approved method 61-02.01. Approximately 0.044 lb of head rice was ground into flour using a cyclone mill with a 0.02-in. sieve (model 2511, Udy Corp., Fort Collins, Colo.). Then, 0.0055 lb of rice flour was put in a convection oven at 266 °F for 1 h to determine the MC of the flour (Jindal and Siebenmorgen, 1987). After MC determination, 0.0066 lb of flour sample (at approximately 12% MC) was mixed with 25 mL of deionized water. Water corrections were made to account for the sample MC being above or below 12%. The rice flour viscosities were then determined using a viscometer (RVA-Super 4; Newport Scientific, Warriewood, NSW, Australia).

Statistical Analyses: Analysis of variance (ANOVA), Tukey's honest significant difference (HSD), and full factorial tests were done using a JMP software Pro 15.0 (SAS Institute, Inc., Cary, N.C.). The significance level (α) was set at 5% for comparing means.

Results and Discussion

Peak Viscosity: Figure 1 shows the peak viscosity of rice flour after treatment with IR heat at different intensities. The maximum viscosity of starch during cooking, which is an indication of water-binding or holding capacity, is known as the peak viscosity. The control sample had an initial peak viscosity of 2511.67 centipoise (cP). The sample treated using an IR intensity of 83.06 BTU/min ft^2 for 30 s had a peak viscosity of 1997.33 cP (i.e., a reduction of 514.34 cP). All other treatment combinations had no significant effect ($P > 0.05$) on the peak viscosity of the sample.

Final Viscosity: Figure 2 shows the final viscosity of samples treated with IR heat intensities. The viscosity of starch after cooking and cooling is referred to as the final viscosity. The sample had an initial final viscosity of 2902 cP. A treatment combination of IR intensity of 83.06 BTU/min.ft^2 for 30 s was the only treatment combination that had a significant effect on the final viscosity. The final viscosity of the sample treated with an IR intensity of 83.06 BTU/min.ft^2 for 30 s was 2592.5 cP.

Trough Viscosity: Trough viscosity is the least viscosity value between peak and final viscosity. Figure 3 shows the effect of IR heat intensities on the trough viscosity of the sample. The initial trough viscosity of the sample was 1474.33 cP. All the treatment combinations tested did not have significant effects on the trough viscosity of the sample ($P > 0.05$).

Breakdown Viscosity: Figure 4 shows the effect of IR heat intensities on rice breakdown viscosity. Breakdown viscosity is the difference between peak viscosity and trough viscosity, which is a measure of the degree of starch granule disintegration. A treatment using an IR intensity of 83.06 BTU/min ft^2 for 30 s reduced the breakdown viscosity of rice from 1037.33 to 619 cP. Other IR intensities tested had no effect on the sample breakdown viscosity.

Setback Viscosity: Figure 5 shows the effect of IR heat intensities on rice setback viscosity. The setback viscosity is the difference between final viscosity and trough viscosity, which is a measure of starch retrogradation ability. Treatment combinations of 83.06 BTU/min ft^2 for 20 and 30 s raised the setback viscosity of the sample from 390.33 cP to 550.67 and 595.17 cP, respectively.

Peak Time: Figure 6 shows the impact of IR heat intensities on rice peak time. Peak time is the time (mins) required to reach peak viscosity, which is an indication of cooking time. The sample treated using IR heat intensity of 83.06 BTU/min ft^2 for 10 and 20 s increased the peak time from 5.82 mins to 5.96 and 5.93 mins, respectively. Other tested treatment combinations had no significant effect on the peak time of rice ($P > 0.05$).

Pasting Temperature: Figure 7 shows the pasting temperature of rice flour after treatment with IR heat intensities. Pasting temperature is the temperature at which viscosity starts to increase. The initial pasting temperature of the sample was 184.19 °F. The sample treated at IR intensity of 83.06 BTU/min ft^2 for 30 s had a pasting temperature of 192.15 °F, an increase of 7.96 °F.

Practical Applications

Since the IR heating technique is a novel approach to rapidly drying and decontaminating rice, it is important to study the effects of IR heat intensity on dried rice quality. This study gives an insight into the effect of IR heat intensities on rice pasting property. The highest IR heat intensity (83.06 BTU/min ft^2) and highest heating duration (30 s) had the most impact on the rice pasting properties. The information in this study will serve as a guide for growers and industry on the IR heat technique parameters that will result in obtaining high-quality and safe rice. Hence, the damage to rice qualities will be drastically minimized, and profitability improved.

Acknowledgments

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Table 1. Experimental design and processing parameters of treatments using selected infrared (IR) wavelengths; µin. represents microinches

IR Heating Duration (s)	IR Peak wavelength $\lambda_{temp\ °F}$ (µin.)	Product-to-emitter distance (in.)	IR Intensity (BTU/min ft^2)
10		4.33	8.19
20	λ_{439} (228.3)	10.83	5.82
30		17.32	3.86
10		4.33	21.84
20	λ_{698} (177.2)	10.83	15.17
30		17.32	9.83
10		4.33	83.06
20	λ_{1170} (126.0)	10.83	53.29
30		17.32	38.43

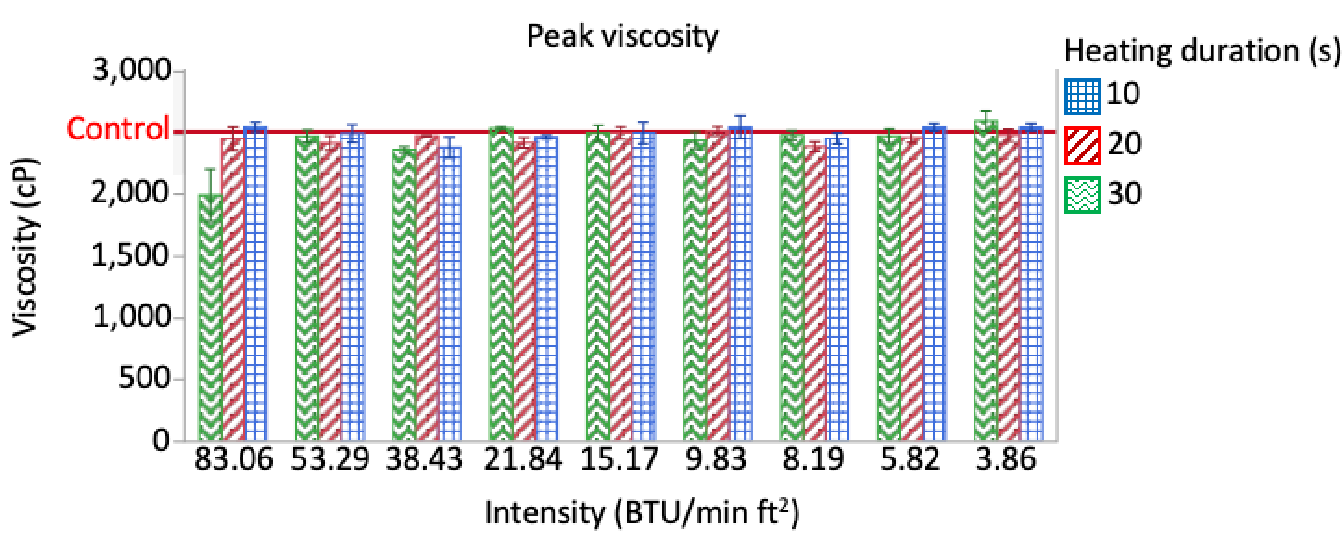

Fig. 1. The effect of infrared heat treatment using selected infrared wavelengths at different infrared intensities, for different heating durations, on rice peak viscosity; cP signifies centipoise.

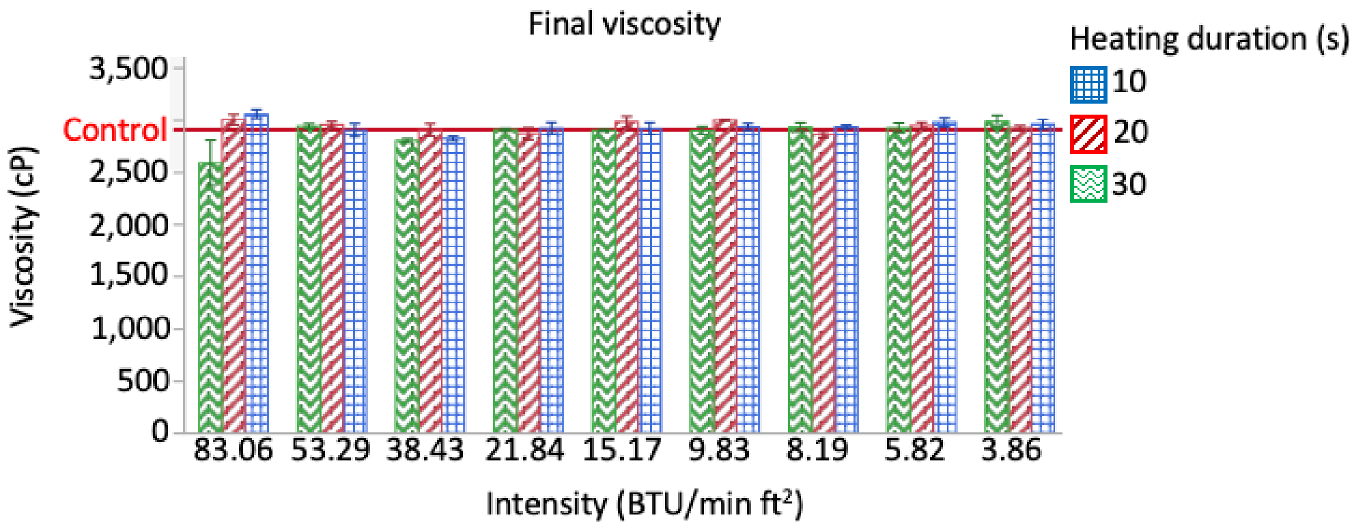

Fig. 2. The effect of infrared heat treatment using selected infrared wavelengths at different infrared intensities, for different heating durations, on rice final viscosity; cP signifies centipoise.

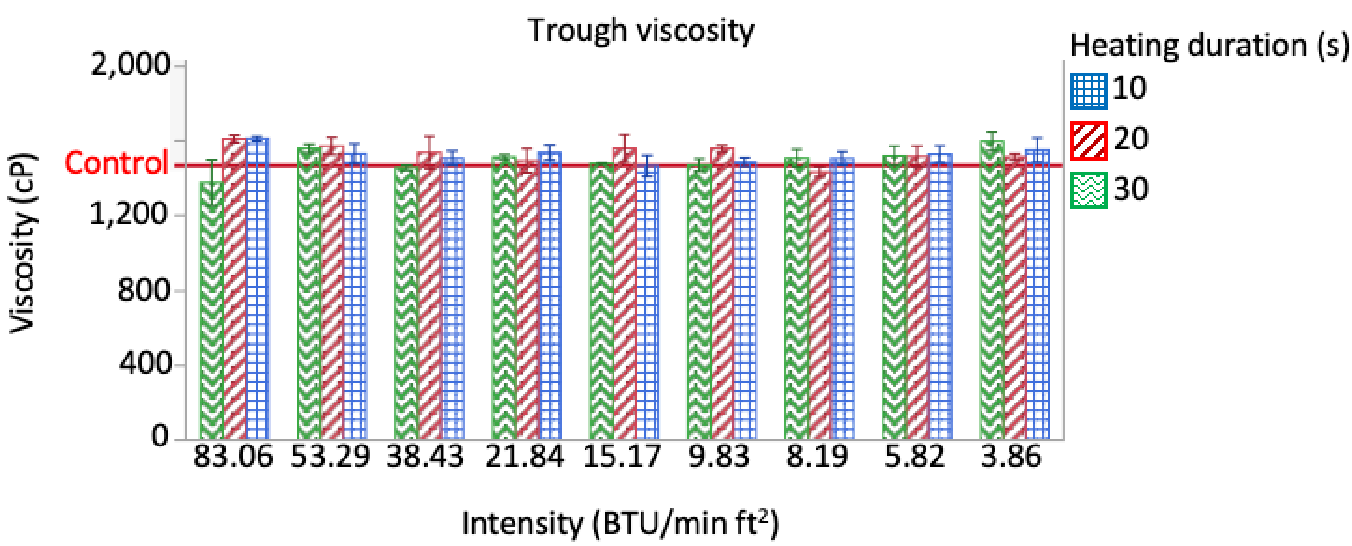

Fig. 3. The effect of infrared heat treatment using selected infrared wavelengths at different infrared intensities, for different heating durations, on rice trough viscosity; cP signifies centipoise.

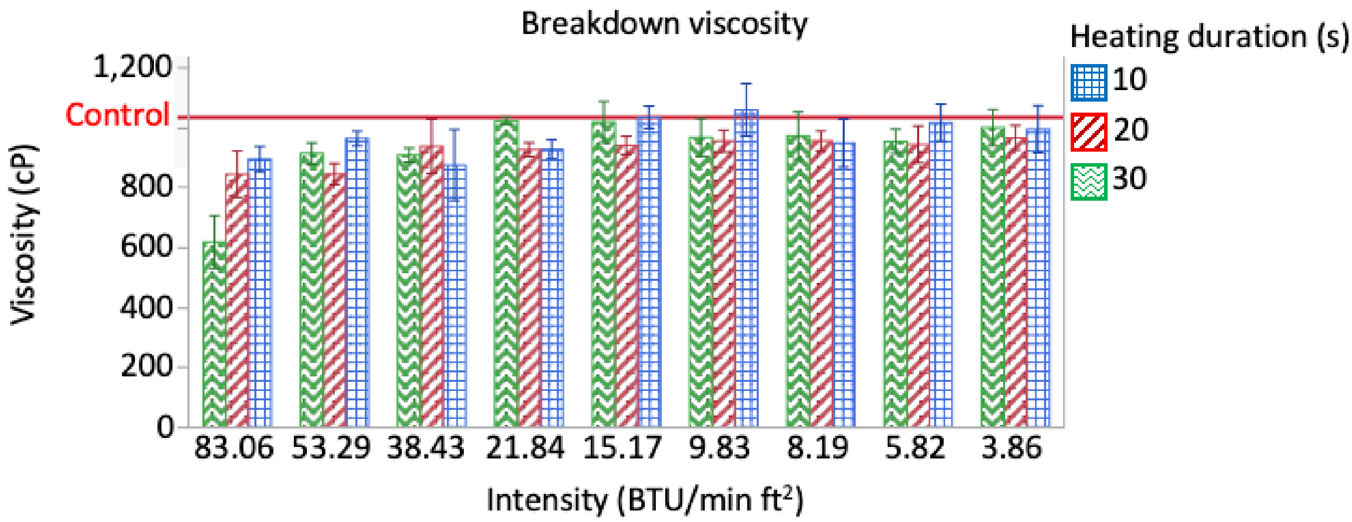

Fig. 4. The effect of infrared heat treatment using selected infrared wavelengths at different infrared intensities, for different heating durations, on rice breakdown viscosity; cP signifies centipoise.

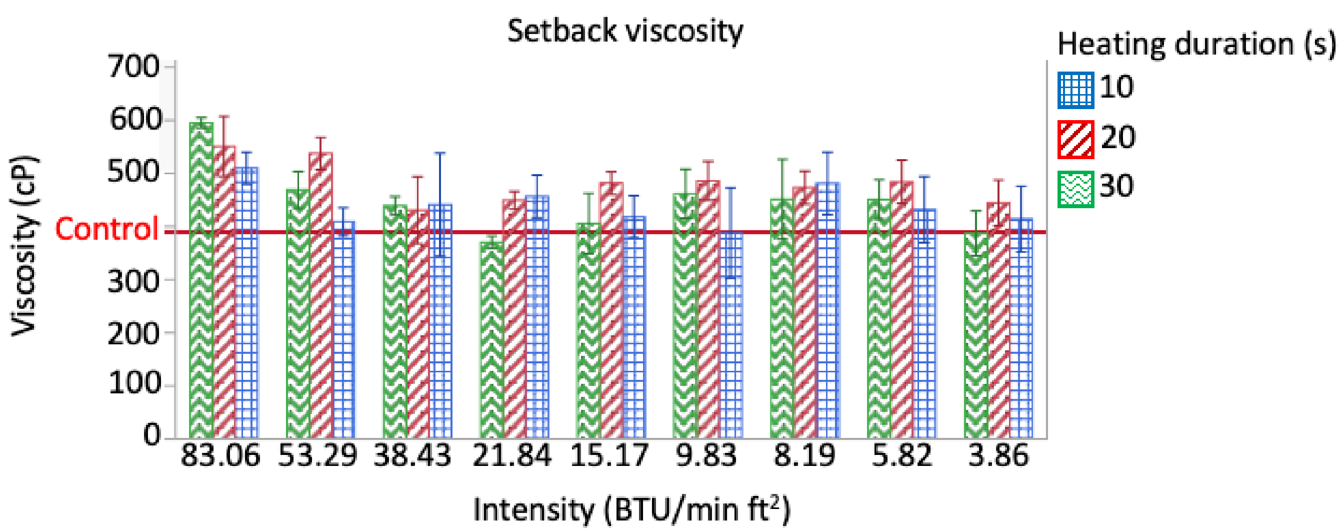

Fig. 5. The effect of infrared heat treatment using selected infrared wavelengths at different infrared intensities, for different heating durations, on the setback viscosity of rice; cP signifies centipoise.

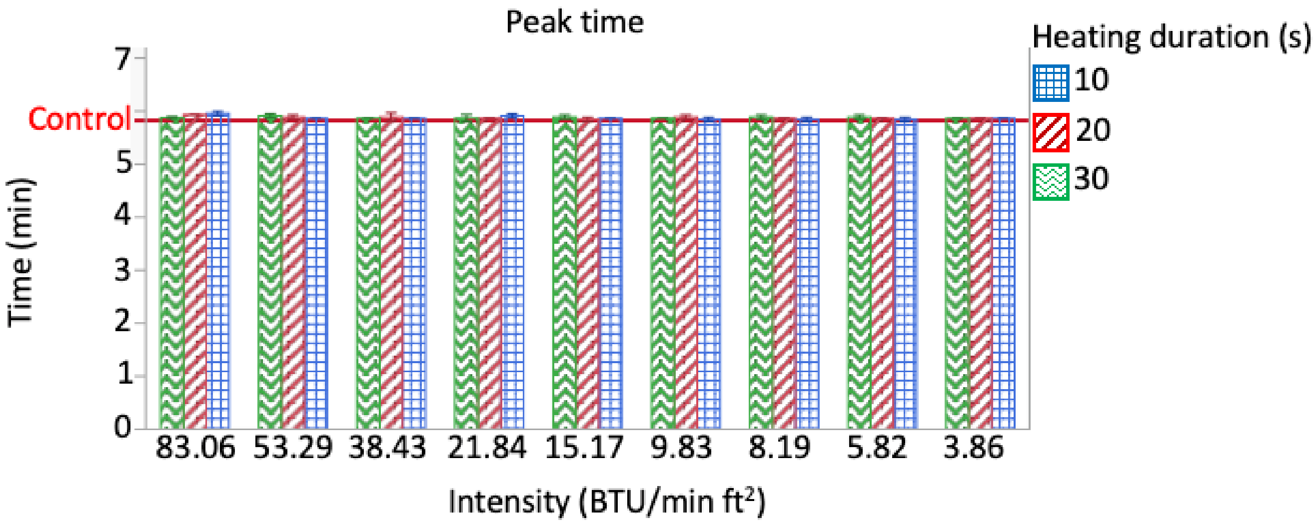

Fig. 6. The effect of infrared heat treatment using selected infrared wavelengths at different infrared intensities, for different heating durations, on the peak time of rice; cP signifies centipoise.

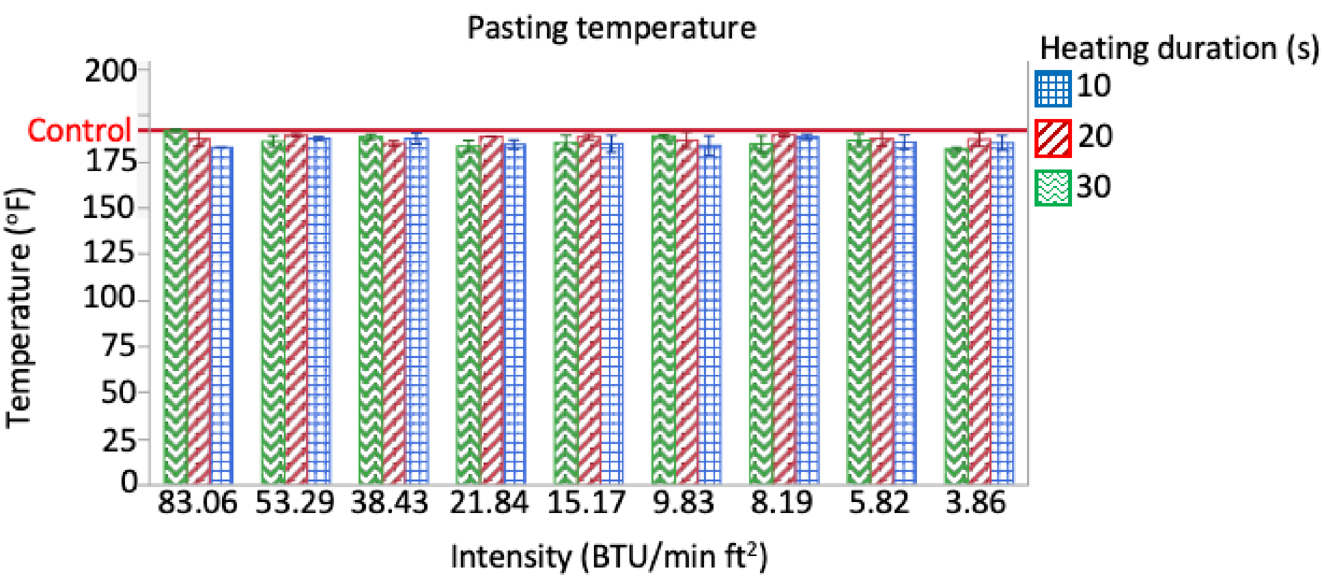

Fig. 7. The effect of infrared heat treatment using selected infrared wavelengths at different infrared intensities, for different heating durations, on the pasting temperature of rice; cP signifies centipoise.

Modeling Moisture Movement Characteristics in Rough Rice Subjected to Chilling Environment

G.G. Atungulu,[1] S. Shafiekhani,[1] and A.A. Oduola[1]

Abstract

While chilling aeration technology for grains has found use in other countries, application for use in the U.S. for rice has been hampered due to lack of scientific and industry-relevant data. The aim of this study is to determine the adsorption and desorption kinetics of rough rice in a chilled environment; such data is vital for automated grain condition monitoring and control of aeration systems at chilled rice conditions. Adsorption and desorption isotherms of hybrid long-grain rough rice (RT CLXL745) subjected to temperatures that are typical in field chilled storage conditions (41 and 86 °F) were measured. The dynamic vapor sorption analyzer (IGAsorp) consisting of microbalances in a controlled atmosphere was used to generate predictive isotherms. Changes in sample weight were continuously monitored across a range of equilibrium relative humidity (10–70%) until a steady-state mass was attained. Non-linear regression analysis was used to estimate empirical constants of 5 models (modified Chung-Pfost, modified Henderson, modified Oswin, modified Halsey, and modified GAB) used for describing grain sorption isotherms. The modified Chung-Pfost equation best described the experimental data with RMSEs of 0.557 and 0.912 for adsorption and desorption data, respectively. All 5 prediction models were in good agreement for experimental data at high-temperature conditions (e.g., at 86 °F). The results indicated that it is more accurate to use newly developed constants for EMC models of rice in a chilled environment than obtaining such data from extrapolations using conventional models.

Introduction

Chilling aeration of high-moisture rough rice may permit short- to long-term storage management of the grain independently of ambient temperature and relative humidity (RH) conditions. Mathematical models have been used to design and optimize equipment involved in the chilling aeration process (Iguaz et al., 2003). Since the equilibrium moisture content (EMC) is dependent on the temperature and RH of the surrounding air, it is important to investigate how changes in temperature and RH influence the EMC of rice under chilling environment (Goneli et al., 2007).

The static method is widely used to determine the EMC isotherms for rough rice, but this method is time-consuming and may be unreliable (Choi et al., 2010; Iguaz and Versade, 2007; Rahman and Sablani, 2009). However, the dynamic vapor sorption (DVS) method may be used to overcome the limitations of the static method. The DVS method is a faster and more accurate approach than the static method. The DVS method significantly differs from the static method in a water activity range of 0.4–0.8 (Bingol et al., 2012; Schimdt and Lee, 2012).

In thin-layer drying, all rice kernels are exposed to identical drying air conditions (Prakash and Siebenmorgen, 2018). ASABE Standard S448.2 (ASABE Standards, 2014) defined 3 layers of kernels as maximum layer depth for thin-layer drying. The parameters of thin-layer drying equations depend upon rice properties including harvest MC, chemical composition, dimensions, drying temperature, RH, and air velocity (Cnossen et al., 2002; Prakash et al., 2011). Mathematical equations have been developed for describing and predicting the isotherms of hybrid long-grain rice; however, these equations do not consider conditions rice is subjected to during chilling under field environments.

The objectives of this study were to: (1) measure the adsorption and desorption isotherms of long-grain rough rice subjected to a chilled environment; and (2) evaluate the appropriateness of thin-layer drying equations for estimating equilibrium data of rough rice.

Procedures

Rice Sample

A hybrid long-grain rice cultivar RT CLXL745 was harvested from Arkansas in 2018. The samples were cleaned and refrigerated at 39.2 °F. Prior to the EMC determination experiments, 300 kernels (100 kernels for each replicate) were randomly selected, and the MC of the subsample was measured using a single kernel moisture meter (Shizuoka Seiki CTR 800A). The samples were then double bagged in sealable plastic bags and refrigerated at approximately 39.2 °F until testing.

Test System

The DVS analyzer (IGAsorp, Hiden Isochema Ltd., Warrington, U.K.) was used to obtain the EMC of rough rice. The IGAsorp is an ultrasensitive electro-balance with 0.05-µg resolution and a 1-g weighing capacity. The RH is controlled within the IGAsorp by measuring a combination of dry and wet nitrogen (N_2) streams. The sample chamber and the solvent reservoir are controlled at the same temperature using a temperature-controlled water bath. The isothermal kinetics of the sample were studied at a

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chilling temperature of 41 and 59 °F. Another run was conducted at 86 °F for model comparisons and validations. For each temperature, 3 rice kernels were placed onto the pan of the equipment. The RH was changed from 10% to 70% and then back to 10% to capture adsorption and desorption isotherms of the sample. The HIsorp software program intelligently controls the IGAsorp reservoir temperature to achieve the target flow rate (250 mL/min N_2) and RH conditions. Before running the isotherm tests, all the samples were gently conditioned by the IGAsorp, which was programmed at 78.8 °F and 56% RH to attain the same starting EMC.

Thin Layer Mathematical Models

Moisture sorption isotherms of the rough rice sample at chilled environments were modeled as $M_e = f(RH,T)$. Results of rough rice MC during adsorption and desorption versus temperature and RH were analyzed using non-linear regression in JMP Pro 14 (SAS Institute Inc., Cary, N.C.) to estimate the empirical constants (*A, B*, and *C*) of the mathematical equations listed in Table 1.

Statistical Analysis

A non-linear regression analysis was done. The root means square error (RMSE) between the predicted and measured EMC results were calculated and compared. An Excel software (Microsoft Office 2019, Microsoft Corp., Redmond, Wash.) was used to calculate the Percent bias (PBIAS). RMSE and PBIAS were calculated as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(M_e^i - M_p^i)^2}{N}}$$

$$PBIAS = \frac{\sum_{i=1}^{N}(M_e^i - M_p^i) * 100}{\sum_{i=1}^{N}(M_e^i)}$$

where M_e is the experimental EMC, M_p is the predicted EMC, N is the number of experimental data point, and i is the i^{th} data point out of the N total points.

Results and Discussion

Moisture Sorption Isotherms

Figure 1 shows the sorption isotherms of the sample at a chilled environment and RHs ranging from 10% to 70%. The results show that at a constant temperature, there is a positive correlation between EMC and the %RH of the rough rice. These results indicate that the sorption relation of rice can be reasonably elucidated by a sigmoidal shape which has been observed by Atungulu et al. (2016). Table 2 shows the temperature, RH, and the EMC values for the sample experimental data obtained for desorption and adsorption, and hysteresis magnitudes. Comparing the EMC values for desorption and adsorption at all air conditions, we can conclude that values acquired for desorption are always higher than those obtained for adsorption. According to Table 2, hysteresis magnitudes decrease as temperature increases, which was also reported by Benado and Rizvi (1985). The EMC values of rice decreased as the temperature increased at a constant RH. The impact of temperature on the sorption capacity of rice was less in the adsorption data compared to the desorption data.

Figure 2 illustrates the effects of different isotherms at different RHs and temperatures on the moisture ratio of rough rice. All the drying curves showed that the whole drying of rough rice occurs in the falling rate period. The results showed that the rice kernels absorb and desorb moisture faster when the RH is high. It is clearly seen from Figure 2 that rice kernels at 41 °F with 10% RH absorb and desorb moisture slowly.

Modeling Sorption Isotherm

The parameters of the sorption models for the adsorption and desorption of the rice sample with the RMSE are presented in Table 3. Based on minimizing RMSE, for temperatures ranging from 41 to 86 °F and RHs from 10% to 70%, the modified Chung-Pfost equation was found to be the most accurate model for describing EMC for both adsorption and desorption data of rice samples. However, the modified Oswin and modified Halsey equations gave nearly identical RMSE values for adsorption (<0.95) and desorption data (<1.2).

Sorption isotherms of rough rice determined by the EMC equations for temperatures of 41, 59, and 86 °F are shown in Fig. 3. The experimental EMC values at 41ºF were generally more than those of predicted equations, especially at RH less than 40%. However, no significant differences were observed between the measured rough rice EMCs and EMCs predicted from the equations at 86 °F and all RHs.

Based on the RMSE results, a modified Chung-Pfost equation is recommended to describe the EMC isotherms of rice in the range of experiments (41–86 °F and 10–70% RH).

Table 4 shows the PBIAS values between measured EMC values and predicted EMC values from the modified Chung-Pfost equation for temperatures at 41, 59, and 86 °F. The PBIAS results show that predicted EMC values were higher than the actual EMC values by 14.8% and 8.7% for samples at 41 and 59 °F, respectively. However, the PBIAS value at temperature 86 °F is negative, which means that the model underestimates the results by 7.9%. Since the values closer to zero are preferred for PBIAS, the modified Chung-Pfost equation accurately predicted rough rice EMC values at temperatures higher than 59 °F.

Practical Applications

The paucity of scientific reports on chilling aeration technology in the U.S. has hampered its adoption by the rice processors. This study provides an understanding of the adsorption and desorption isotherm behaviors of rough rice in the range of temperatures and RHs commonly used in chilling aeration processes. The knowledge of the drying kinetics and EMCs of rough rice at chilled environment could allow rice processors to determine the optimum processing conditions during chilling aeration and improve automated monitoring of rice moisture, temperature and quality conditions.

Acknowledgments

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Table 1. Equilibrium moisture content models used for describing grain sorption data.

Equation	Equilibrium Moisture Content Model
Modified Chung-Pfost (Chung and Pfost, 1967)	$M_e = \frac{-1}{C} \ln\left[\left(\frac{-(T+B)}{A}\right) \ln RH\right]$
Modified Henderson (Henderson, 1952)	$M_e = \left[-\frac{ln(1-RH)}{A(T+B)}\right]^{\frac{1}{C}}$
Modified Halsey (Halsey, 1948)	$M_e = \left[-\frac{exp(A+B\ .\ T)}{\ln RH}\right]^{\frac{1}{C}}$
Modified Oswin (Oswin, 1946)	$M_e = (A+B\ .\ T)\left[\frac{RH}{1-RH}\right]^{\frac{1}{C}}$
Modified GAB (Jayas and Mazza, 1993)	$M_e = \frac{A\ .\ B\ .\left(\frac{C}{T}\right)\ .\ RH}{(1-B\ .\ RH)\left[1-B\ .\ RH+\left(\frac{C}{T}\right).B\ .RH\right]}$

Table 2. Equilibrium moisture content experimental values for adsorption, desorption and hysteresis of long-grain hybrid rice cultivar RT CLXL745.

Temperature (°F)	RH (%)	EMC of adsorption (% d.b.)[a]	EMC of desorption (% d.b.)	Hysteresis (% d.b.)
41	10	11.6	13.4	1.8
41	50	15.6	16.8	1.2
59	10	8.2	9.8	1.6
59	40	11.9	13.0	1.1
86	10	5.5	5.6	0.1
86	40	8.7	9.9	1.2

[a] d.b. = dry basis.

Table 3. Estimated coefficients of the modified Chung-Pfost, modified Henderson, modified Halsey, modified Guggenheim Anderson DeBoer (GAB), and modified Oswin equations, and the statistical parameters used to evaluate the models. RMSE has unit % (d.b.), which is the same as the unit of the response variable (equilibrium moisture content) of the regression model.

		Estimated Model Constant			Statistical Coefficient
Model	**Isotherm**	**A**	**B**	**C**	**RMSE**
Modified Chung-Pfost	Adsorption	297.4197	4.8974	0.2340	0.557
	Desorption	383.3781	0.4815	0.2630	0.912
Modified Henderson	Adsorption	$3.1561e^{-6}$	3.2386	3.6403	1.213
	Desorption	$8.1625e^{-8}$	-2.977	5.3102	1.682
Modified Halsey	Adsorption	8.0843	-0.052	2.9750	0.855
	Desorption	10.9296	-0.091	3.7926	1.196
Modified GAB	Adsorption	14.6168	0.2844	430.30	1.318
	Desorption	17.4294	0.0005	249273.28	1.307
Modified Oswin	Adsorption	17.1191	-0.225	4.6861	0.947
	Desorption	18.7899	-0.317	6.8906	1.176

Table 4. Comparison of percent biases (PBIASs) of experimental and predicted equilibrium moisture content (% dry basis) values for rough rice at 41 to 86 °F and 10% to 70% relative humidity (RH).[a]

		Equilibrium Moisture Content (% dry basis)		
Temperature	**Relative Humidity**	**Present study**	**Modified Chung-Pfost**	**PBIAS**
(°F)	**(%)**			**(%)**
41	10	12.5	8.9	14.8
	30	13.5	11.7	
	50	16.2	14.2	
	70	18.7	17.1	
59	10	9.0	7.6	8.7
	40	12.5	11.6	
	70	16.8	15.8	
86	10	5.5	6.1	-7.9
	40	9.3	10.2	
	70	13.7	14.3	

[a] Each value is an average of adsorption and desorption for each condition.

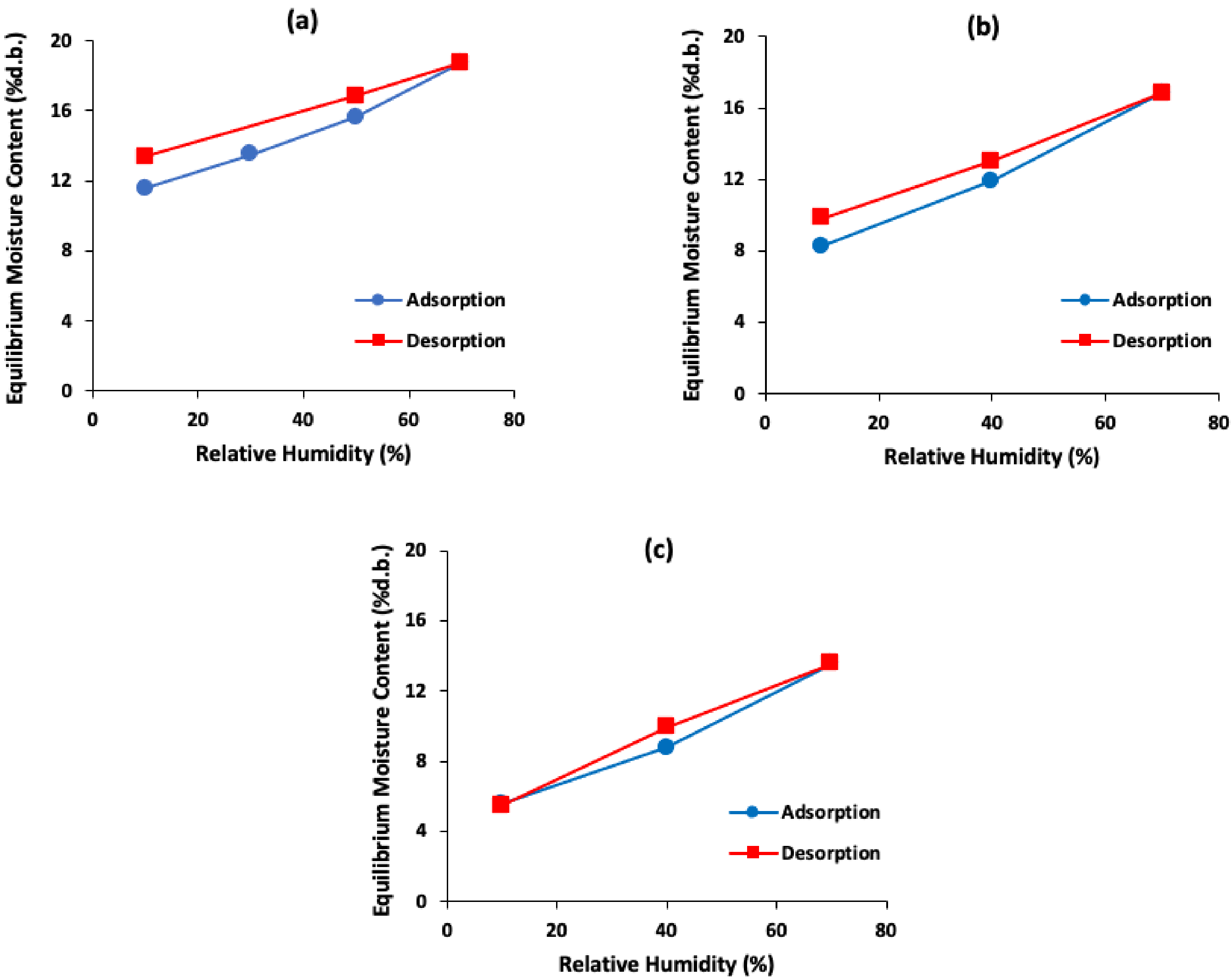

Fig. 1. Sorption isotherms of long-grain hybrid rice cultivar XL-745 at (a) 41 °F (b) 59 °F, and (c) 86 °F.

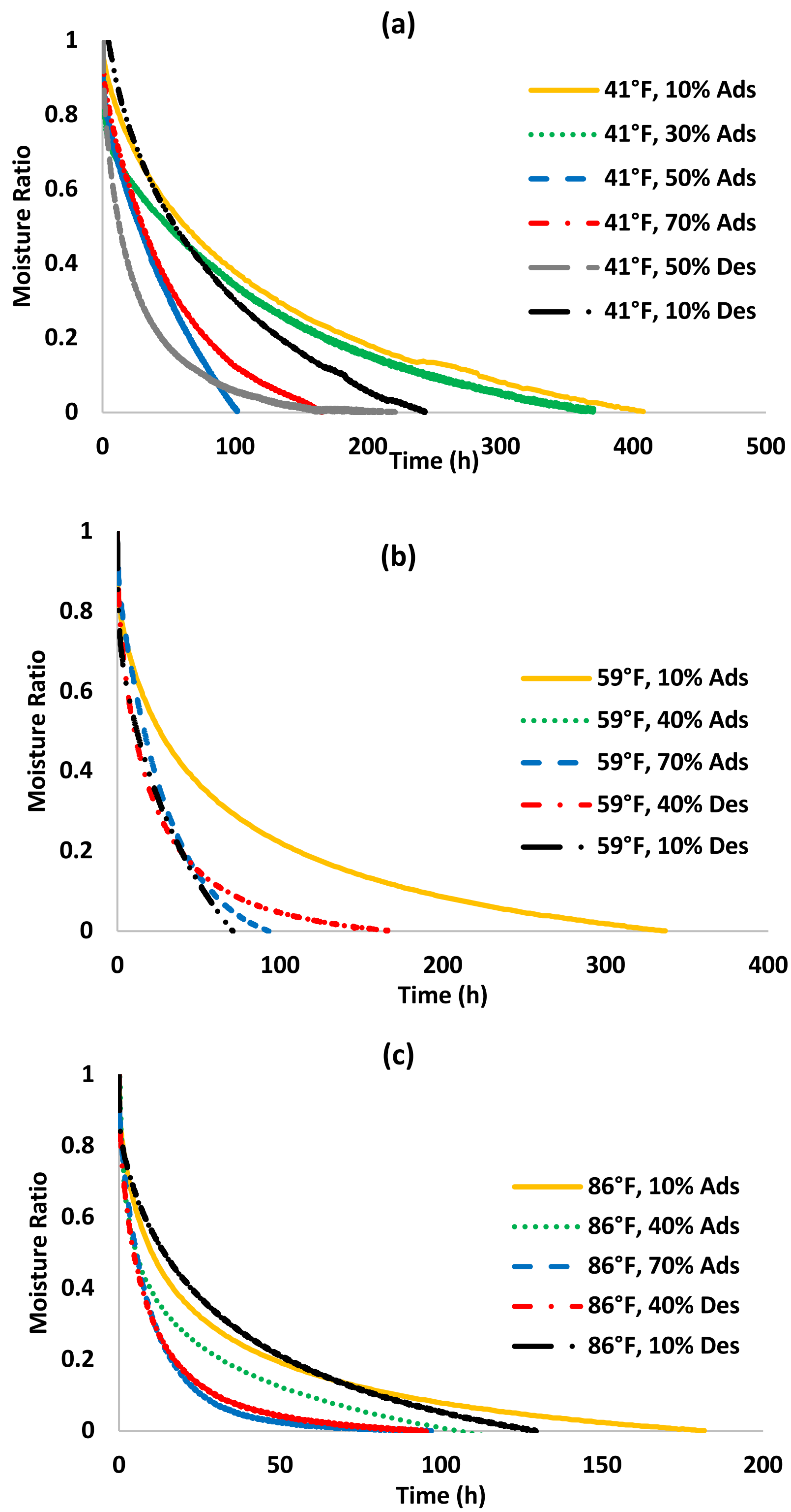

Fig. 2. Comparison of moisture ratios of long-grain hybrid rice cultivar RT CLXL745 at different drying air conditions: (a) 41 °F, (b) 59 °F, and (c) 86 °F. Ads and Des indicates adsorption and desorption, respectively.

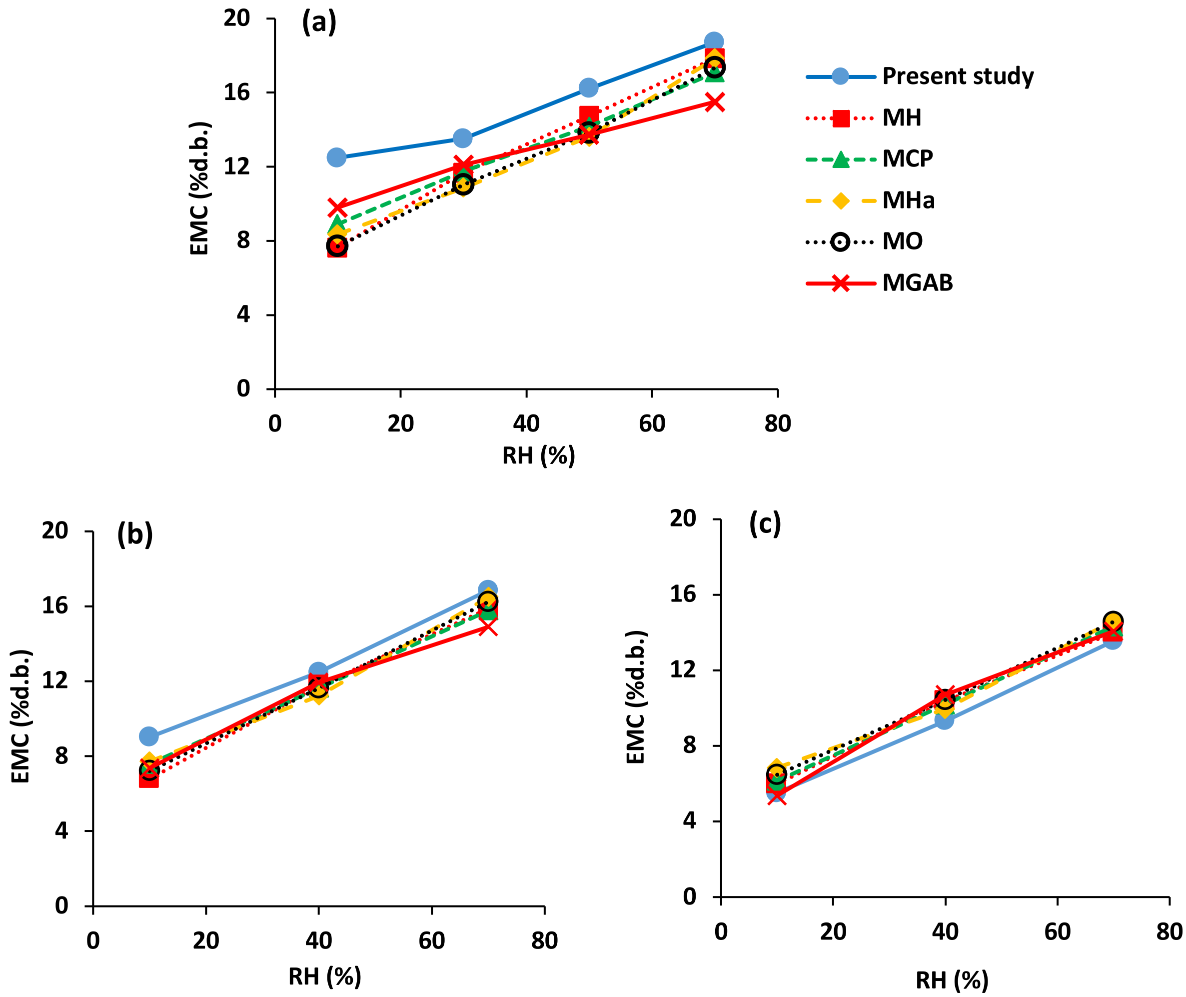

Fig. 3. Equilibrium isotherms (expressed on a dry basis) from the present study compared to data predicted by modified Henderson (MH), modified Chung-Pfost (MCP), modified Halsey (MHa), modified Oswin (MO), and modified Guggenheim Anderson DeBoer (MGAB) for: (a) 41 °F, (b) 59 °F, and (c) 86 °F. EMC indicates equilibrium moisture content; RH indicates relative humidity; d.b. indicates dry basis.

Quantifying Milling Effects on Paste Viscosities, Gelling Rates, and Gelatinization Temperatures of Popular Arkansas Rice Cultivars

S. Graham-Acquaah,[1] T.J. Siebenmorgen,[1] R.A. January,[1] S. Scott,[1] and G.G. Atungulu[1]

Abstract

As part of an ongoing research effort to enhance rice utilization in food product development, this study determined paste viscosities, gelling rates, and gelatinization temperatures of brown and white (milled) flour samples of Arkansas rice cultivars and quantified the impact of milling on these end-use properties. The results show that there could be more changes in end-use properties when rice is milled than inherent differences among cultivars. Combining cultivar selection with optimized milling could thus enhance rice utilization in product development. This information provides insight to rice breeders and processors on cultivar attributes and milling effects on end-use functionality.

Introduction

Interest in rice flour for food-product development is growing concurrently with the emerging gluten-free market. The rice industry in Arkansas has yet to capitalize on this growing market because rice producers and processors do not have readily accessible information on end-use characteristics of local cultivars to enable them to develop new products and optimize processing methods. End-use requirements vary depending on the food product. Consistently evaluating and documenting differences among local cultivars is necessary for cultivar selection and optimization of processing methods for specified end-uses. Information on end-use attributes of Arkansas cultivars, aside from being relatively sparse, has been mostly generated on milled-rice-flour. However, proteins and lipids, the major constituents of the bran layer of rice removed during milling, are known to affect end-use properties (Patindol et al., 2003; Derycke et al., 2005; Saleh and Meullenet, 2007). Furthermore, total protein and lipid contents vary among Arkansas rice cultivars (Graham-Acquaah et al., 2020) suggesting that milling could affect end-use properties to different degrees.

Gelatinization temperature (GT) is a key indicator of end-use quality. The GT of a cultivar refers to the critical temperature value at which its starch granules begin to melt and undergo irreversible changes in structure. It usually provides an indication of the cooking duration. In the parboiling industry, for instance, GT informs soaking and steaming conditions. Aside from GT, paste viscosities (peak, breakdown, and setback) and the rate at which viscosity changes during heating and mixing (rate of pasting), hereby referred to as gelling rate, are also important indicators of processing quality. As part of ongoing studies to identify cultivar attributes that affect rice milling and end-use functionality, the aforementioned properties were determined on brown-rice and milled-rice flour samples of Arkansas cultivars to quantify the impact of milling on end-use quality.

Procedures

Samples of 19 cultivars comprising 17 long-grains and 2 medium-grains, harvested at various moisture contents, were collected from RiceTec show plots at Harrisburg, Ark. in September 2019. Rough rice samples of most cultivars (n = 15) were collected from replicate plots. Each of the 34 rough rice lots was cleaned using a dockage tester (XT4, Carter-Day, Minneapolis, Minn.), then gently dried to 12.5% moisture content on a wet basis. After drying, duplicate 100-g samples of each cultivar were dehulled using a laboratory sheller (THU 35B-3T, Satake, Tokyo, Japan). Afterwards, subsamples of approximately 20 g of brown rice were ground to flour. Another set of 150-g rough-rice samples were first dehulled, then milled for 30 s in a McGill No. 2 laboratory mill; head rice was separated from broken kernels using a shaker table. Subsequently, about 20 g of head rice from each milled sample was ground to flour. Peak, trough, and final viscosities of the brown-rice and milled-rice flour samples were determined using a viscometer (RVA Super 4, Newport Scientific, Warriewood, Australia). Breakdown was calculated as the difference between peak and trough viscosities. Setback viscosity was calculated as the difference between final and peak viscosities. The gelling rate was determined by dividing the peak viscosity by the duration it took to observe the maximum peak (i.e., peak time). The gelatinization temperatures of samples were also determined using an RVA method (Dang and Bason, 2014).

The maximum difference (%) in any end-use property among cultivars (MPD) was estimated as:

$$MPD = \frac{C_{max} - C_{min}}{C_{min}} \times 100\%;$$

where C_{max} and C_{min} are maximum and minimum values of a property for a set of milled rice or brown rice samples of the 19 cultivars.

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The percentage change in a property due to milling (PCM) was determined as follows:

$$PCM = \frac{MR_v - BR_v}{BR_v} \times 100\%;$$

where MR_v and BR_v are the milled rice and brown rice end-use-property values, respectively, recorded for a particular cultivar.

Results and Discussion

Rice lots were grown under identical soil and climatic conditions and harvested on the same day. Differences in harvest moisture content (HMC) were controlled for during data analyses by including HMC as a factor in a least-squares regression to provide an adjustment for different HMCs; end-use properties of cultivars could thus be mainly attributed to genotype or milling induced differences. Table 1 shows, for each property, the minimum, maximum, range, and maximum percentage difference (MPD) among the 19 cultivars. The least MPDs of 13% for brown rice and 16% for milled rice were observed for gelatinization temperature. Setback recorded the greatest MPDs (brown rice = 814%; milled rice = 363%). The MPDs for peak, breakdown, and gelling rates of brown-rice samples were 19%, 183%, and 23% respectively. Among the milled-rice samples, MPD was 16% for peak viscosity, 363% for breakdown, and 30% for gelling rate.

Figure 1 shows peak viscosities of brown and milled samples of the 19 cultivars and the percentage change in peak viscosity of each cultivar resulting from the milling process. The least percentage change on milling (PCM) was 48% (RT 7801); the greatest PCM of 70% was observed for RT 7321 FP. The greater PCM values for peak viscosity compared to its MPDs (Table 1) suggests that the milling process could lead to greater changes in peak viscosity of rice for end-use application than inherent differences among cultivars. Figure 2 shows that milling caused a 30% to 97% change in breakdown viscosity depending on cultivar. In the case of setback, PCMs ranging from 33% to 335% were observed (Fig. 3). The PCMs for breakdown and setback, however, did not exceed their respective MPDs (Table 1). Regarding the gelling rate (Fig. 4), milling caused greater changes (50%–75%) in values than the maximum difference among cultivars (brown rice samples = 23%; milled rice samples = 30%).

Paste viscosities and gelling rate reflect the behavior of flour samples when mixed with water and stirred while heating. Peak viscosity signifies the extent to which the flour, especially the starch component, absorbs water and swells. Breakdown depicts the extent to which the swollen starch granules can withstand continuous stirring before bursting to release water into the slurry leading to a decrease in the viscosity of the slurry. Setback, on the other hand, indicates how viscous the heated slurry could become when cooled. Values of these properties are important for determining the types and quality of products that could be prepared with flour. For instance, flour for noodle production must have restricted swelling and a low breakdown (Collado, 2001). Setback has implications on staling of flour-based products and the hardness of cooked rice. Gelling rate influences the design of apparatus for processing flour-based products and also gives an indication of the role of rice chemical components such as proteins on hydration and gelatinization of flour (Martin and Fitzgerald, 2002)

Figure 5 shows the gelatinization temperatures of the 19 cultivars. The GT of RT 7801 is particularly noteworthy given that it is the only long-grain cultivar with GT < 70 °C, making it a low-GT cultivar (Dang and Bason, 2014). The other cultivars with low GT are Titan and RT 3201 MG, which are medium grains. The remaining were mostly high-GT cultivars (GT > 74 °C) except for CL153 and RT 7501, which based on milled-rice GT-values have intermediate GT (70–74 °C). Milling decreased GT of all cultivars. The percentage change on milling for GT ranged from 0.7% to 4.4%. The maximum percentage difference was 13% for the set of brown-rice samples and 16% for the set of milled-rice samples, suggesting that GT would be best altered through breeding than milling.

Practical Applications

This study quantified the impact of milling on end-use properties of Arkansas rice cultivars. The results provide insight to breeders and processors on cultivar selection and the utilization of milling process for altering properties of rice for end-use applications. The data on brown rice properties would also facilitate the development of rapid methods for predicting end-use quality during breeding and for optimizing postharvest operations for specified end-use applications.

Acknowledgments

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Table 1. Maximum, minimum, range, and maximum percentage difference among end-use properties of sets of brown and milled samples of 19 Arkansas rice cultivars.

		Descriptive statistics			
Form of sample	End-use property	Maximum value	Minimum value	Range	Maximum difference among cultivars (%)
Brown rice flour	Peak viscosity	2168 cP	1823 cP	345 cP	19
	Breakdown	1087 cP	384 cP	703 cP	183
	Setback	1874 cP	205 cP	1669 cP	814
	Gelling rate	368 cP/min	299 cP/min	70 cP/min	23
	Gelatinization temperature	76 °C	67 °C	9 °C	13
Milled rice flour	Peak viscosity	3500 cP	2717	783	29
	Breakdown	1708 cP	755	953	126
	Setback	1264 cP	-482	1746	363
	Rate of pasting	583 cP/min	448 cP/min	135 cP/min	30

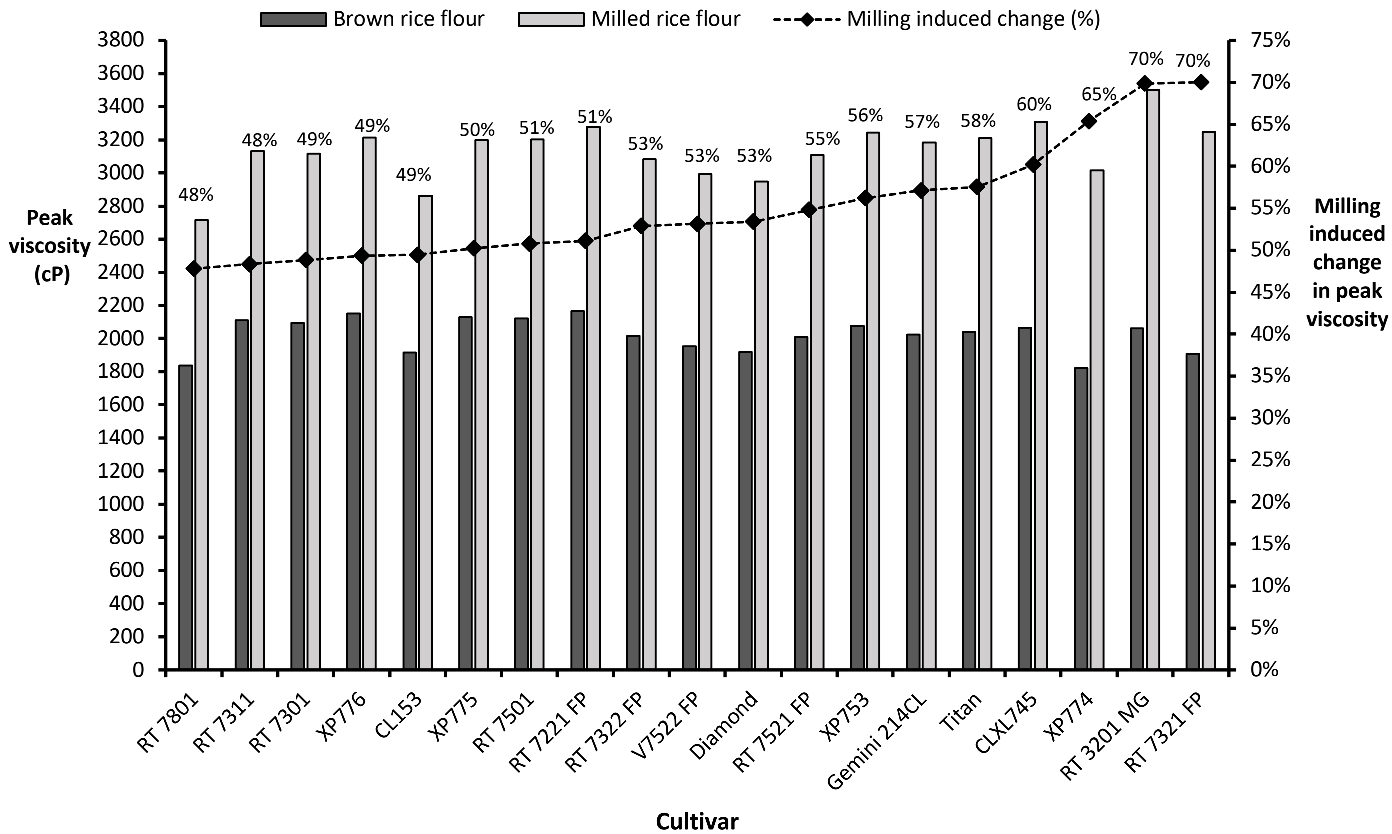

Fig. 1. Peak viscosities (PVs) of brown and milled samples of 19 Arkansas rice cultivars and the percentage milling induced changes in PVs. Each PV value is the mean of duplicate measurements. Note that XP774, 775, and 776 are experimental products.

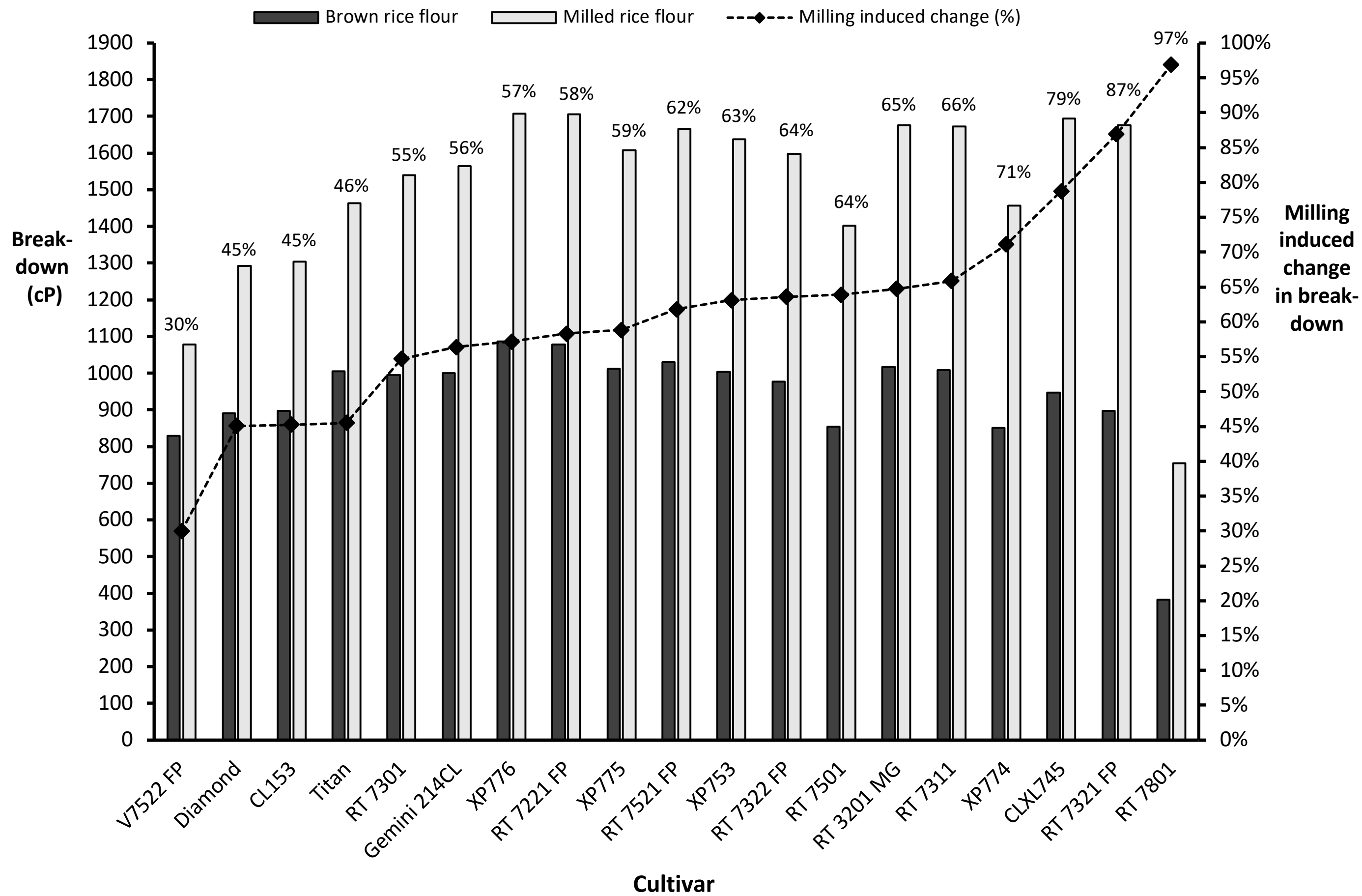

Fig. 2. Breakdown viscosities (BDs) of brown and milled samples of 19 Arkansas rice cultivars and the percentage milling induced changes in BDs. Each BD value is the mean of duplicate measurements. Note that XP774, 775, and 776 are experimental products.

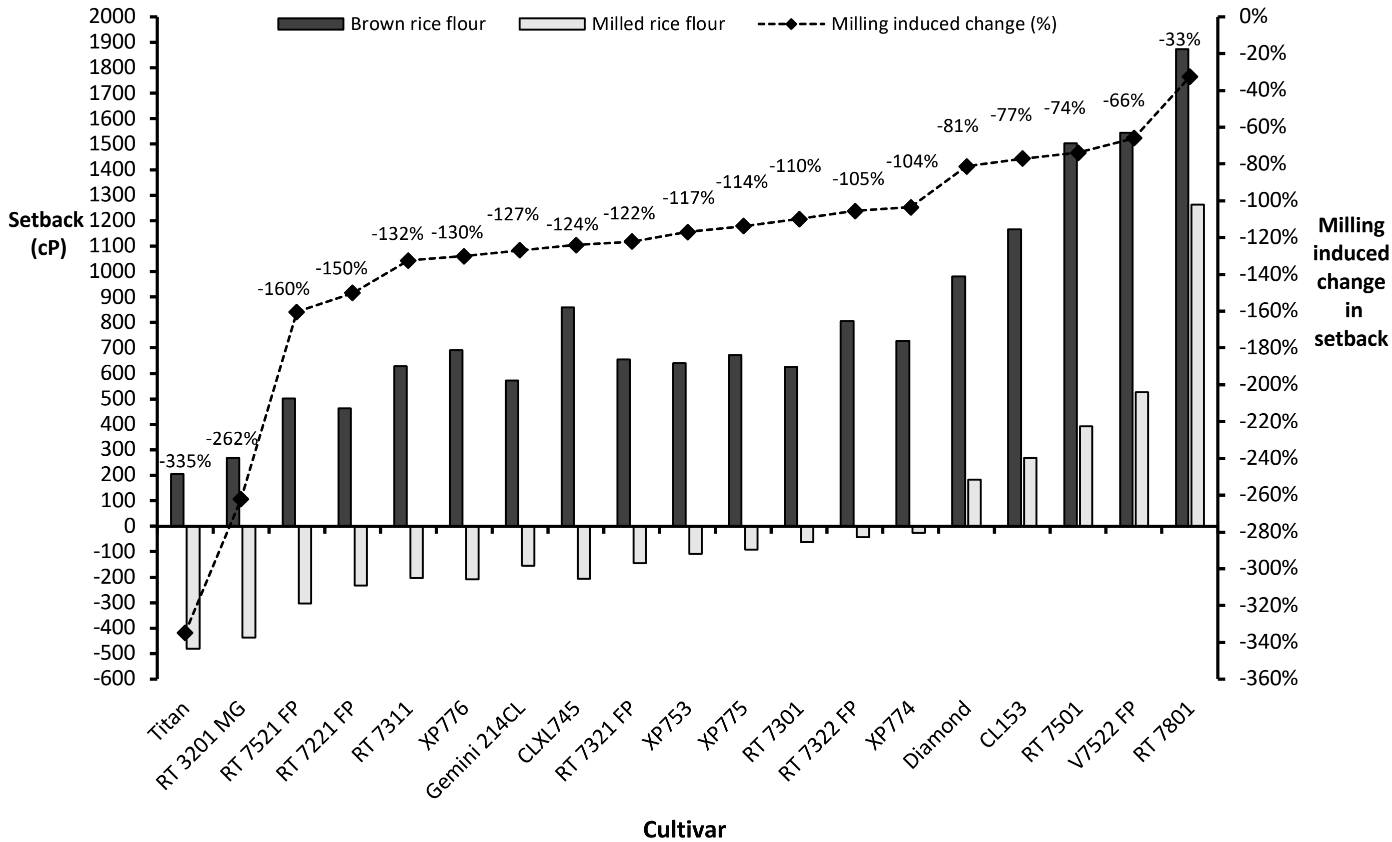

Fig. 3. Setback viscosities (SBs) of brown and milled samples of 19 Arkansas rice cultivars and the percentage milling induced changes in setback viscosities. Each SB value is the mean of duplicate measurements. Negative percentage values suggest decreases in SB values upon milling. Note that XP774, 775, and 776 are experimental products.

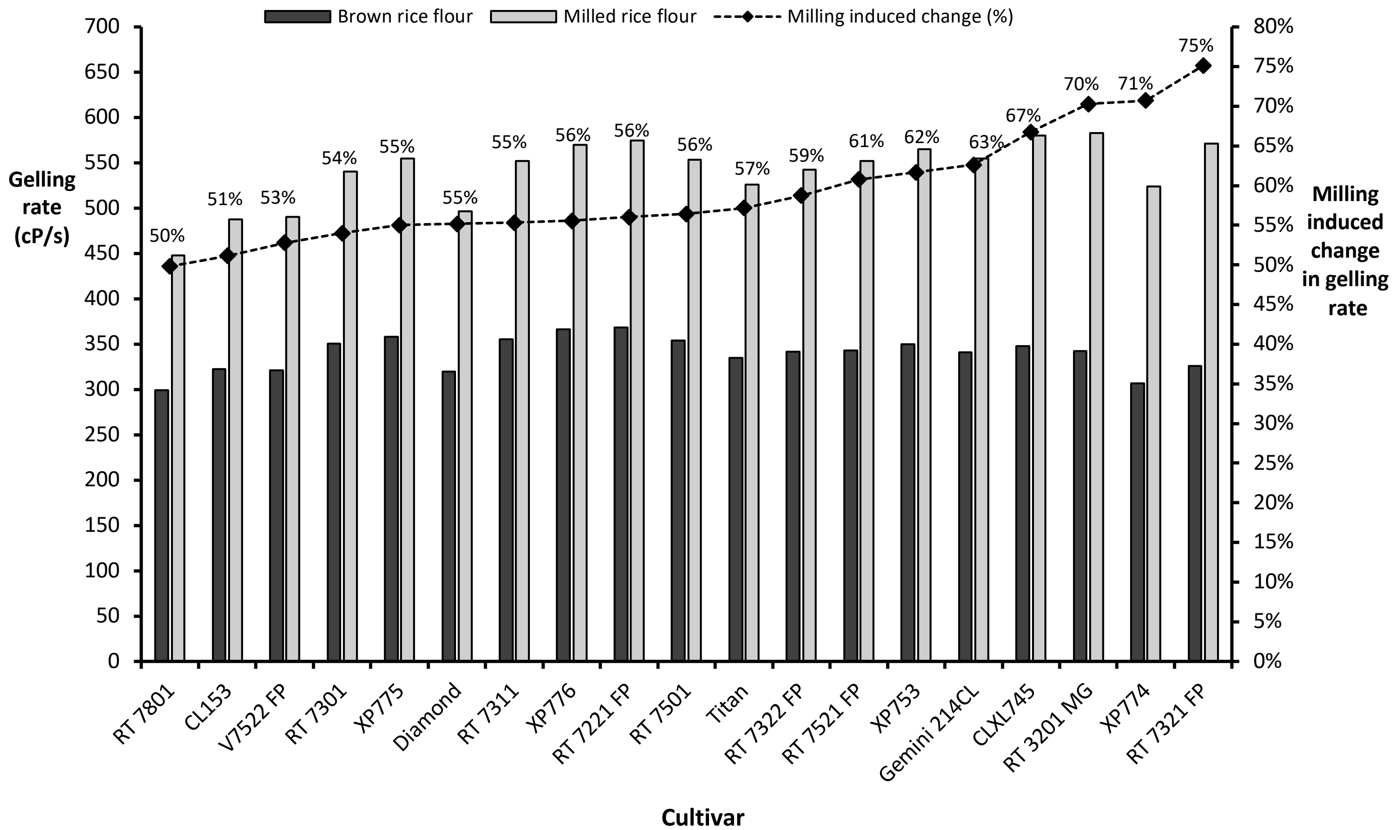

Fig. 4. Gelling rates of brown and milled samples of 19 Arkansas rice cultivars and the percentage milling induced changes in gelling rate. Each gelling-rate value is the mean of duplicate measurements. Note that XP774, 775, and 776 are experimental products.

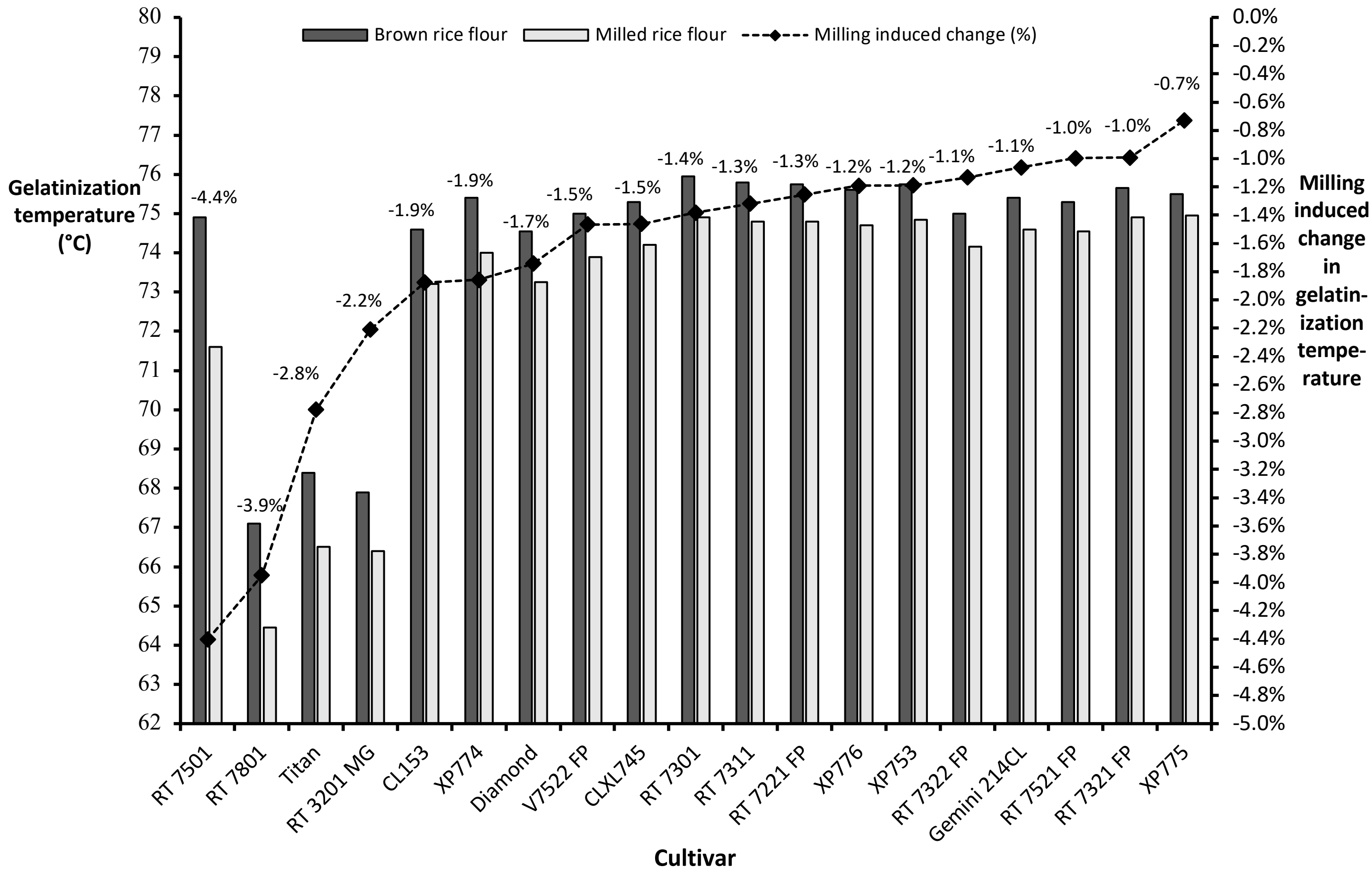

Fig. 5. Gelatinization temperatures (GT) of brown and milled samples of 19 Arkansas rice cultivars and the percentage milling induced changes in GTs. Each GT value is the mean of duplicate measurements. Negative percentage values suggest decreases in GT values upon milling. Note that XP774, 775, and 776 are experimental products.

Processing Parameters for One-Pass Drying of High-Moisture Parboiled Rough Rice with 915 MHz Microwaves

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Abstract

Freshly harvested, long-grain rough rice of the cultivar Mermentau at a moisture content (MC) of 31.58% dry basis (d.b.) was soaked in water at temperatures of 159.8, 163.4, or 168.8 °F and steamed for 5, 10, or 15 mins. After parboiling, control samples of rough rice were gently dried with natural air at 77 °F and 65% relative humidity, while non-control samples were dried using a 915 MHz microwave (MW) dryer, which was set to deliver energy ranging from 61.91 to 448.84 BTU per lb of rough rice dry matter content (BTU.[lb-DM]$^{-1}$). The MW power applied during treatment ranged from 3412 to 27297 BTU/h with heating durations of up to 6 min. The rough rice MC immediately increased after the soaking and steaming processes and ranged from 42.59% to 48.21% d.b. Increased soaking temperature led to increased moisture uptake during soaking, decreases in milled rice yield (MRY), head rice yield (HRY), protein content, and milled rice surface lipid content (SLC), and increases in total color difference (TCD). Increased steaming duration led to decreased moisture uptake during steaming, decreased MRY, protein content, SLC, and TCD, and increased HRY. Increased MW specific energy led to decreased final MC, HRY, protein content, and SLC and increased TCD. It is recommended that long-grain rough rice should be soaked at 163.4 °F, steamed for 10 min, and then treated at MW specific energy of 448.84 BTU.[lb-DM]$^{-1}$ in one pass to achieve parboiled rough rice FMC of 18.79% d.b., HRY of 69.33%, and desirable parboiled milled rice physicochemical and sensory properties.

Introduction

The introduction of a microwave (MW) drying system that can dry high moisture content (MC) parboiled rough rice lots to a safe storage MC of 14.29% to 15.61%, in one pass, with rice milling and physicochemical properties comparable to or better than conventional drying methods could considerably benefit the rice milling industry. However, to successfully dry high-MC parboiled rough rice in one pass using MW while preserving milling yields and quality characteristics, it is vital to investigate the impacts of the pre-drying parboiling conditions on the MW drying process and product characteristics. Therefore, the objectives of this study were to explore the feasibility of using MW at 915 MHz to dry high-MC parboiled rough rice and to determine the implications of pre-drying conditions of soaking and steaming on rough rice final moisture content (FMC), milled rice yield (MRY), head rice yield (HRY), and the parboiled milled rice physiochemical properties, such as protein content, surface lipid content (SLC), and total color difference (TCD).

Procedures

Parboiling

Samples of 7.94 lb of rice were placed in pieces of cheesecloth (17.72 in. × 17.72 in.) and then allowed to soak in a lab-scale hot water bath set to 159.8, 163.4, or 168.8 °F for 3 h. After soaking, the wet rough rice was steamed to complete the physicochemical process of starch gelatinization. The rice samples in cheesecloth were steamed in a lab-scale autoclave set to a temperature of 235.4 °F and pressure of 9.72 psi for 5, 10, or 15 min.

Microwave and Tempering Treatments

The MW system previously described by Smith et al. (2018) was used in this study. For MW treatment, freshly parboiled rough rice samples were placed into MW-safe trays (15.75 × 11.81 × 1.97 in.) for treatment. The bed thickness of the samples was 1.38 in. The samples were treated in batches for 6 min with MW power ranging from 3412 to 27297 BTU/h (Fig. 1). After MW treatment, the samples were immediately tempered by transferring to glass jars and sealed airtight. The jars were placed in an environmental chamber set to 140 °F for 4 h. After tempering, the rice was spread uniformly on trays and transferred to an equilibrium moisture content (EMC) chamber (Platinous chamber, ESPEC North America, Hudsonville, Mich.) set at 77 °F and relative humidity (RH) of 65%. The samples were allowed to cool naturally to 77 °F, and then MC measurements were taken. For the control experiments, rough rice samples (3 replications, 7.94 lb each) were soaked at 159.8, 163.4, or 168.8 °F for 3 h and then steamed at 9.72 psi for 5, 10, or 15 min. The parboiled rough rice samples were then tempered for 4 h at 140 °F. After tempering, the sample was gently dried in an EMC chamber to a MC of 14.29%. The drying duration was 48 h.

Rice Milling

Triplicate 0.33-lb subsamples of parboiled rough rice, obtained from each sample dried to 14.29% MC, were dehulled using a lab huller (Satake Rice Machine, Satake Engineering Co., Ltd., Tokyo, Japan), milled for 30 s using a lab mill (McGill #2 Rice Mill, RAPSCO, Brookshire, Texas), and aspirated for 30 s using a

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seed blower (South Dakota Seed Blower, Seedboro, Chicago, Ill.). MRY was calculated as the mass proportion of parboiled rough rice, including head rice and broken kernels, that remained after milling. Head rice is defined as kernels that retain at least three-fourths of the original kernel length after complete milling (Smith and Atungulu, 2018). HRY was calculated as the mass proportion of parboiled rough rice that remained as head rice after milling.

Crude Protein Determination

Crude protein was measured by scanning 0.11 lb of milled rice kernels using NIR reflectance (NIR, DA7200, Perten Instruments, Hägersten, Sweden) following AACCI Approved Method 39-25.01 for whole grain. The crude protein content is reported as the mass percentage of protein in wet basis relative to the mass of white rice (Grigg et al., 2016).

Surface Lipid Content Determination

Head rice surface lipid content was determined as an indicator of the degree of milling (DOM) using the previously described NIR system. The NIR instrument was calibrated using AACCI Approved Method 30-25.01 (Saleh et al., 2008).

Determination of Color Values

The milled rice color indices ($L*$, $a*$, and $b*$) were measured using a colorimeter (Hunter Associates Laboratory, Reston, Va.). The instrument measures color indices specified by the International Commission on Illumination (CIE). Parameter $L*$ describes the lightness from 100 (light) to 0 (dark), parameter $a*$ describes the red-green color range, and parameter $b*$ describes the yellow-blue color range. The TCD (eq. 1) is a combination of all three CIE parameters that indicate the TCD of the rice kernels after treatment (Anarjan et al., 2012; Xie et al., 2017; Liu et al., 2019):

$$\text{TCD} = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2}$$

where $\Delta L*$, $\Delta a*$, and $\Delta b*$ are the differences in the $L*$, $a*$, and $b*$ values, respectively, between conventionally dried and MW-dried milled rice samples.

Statistical Analysis

Statistical analyses were performed with JMP statistical software v. 15.0.0 (SAS Institute, Inc., Cary, N.C.). A second-order response surface model was used to geometrically describe the relationships between the responses and the experiment parameters. The Prediction Profiler in JMP was used to come up with acceptable operating parameters. All tests were considered to be significant when $P < 0.05$.

Results and Discussion

Implications of Soaking Temperature and Steaming Duration on Moisture Content, Milled Rice Yield and Head Rice Yield

Table 1 shows the least-square (LS) means and standard deviations (SD) of the control samples' MC, MRY, and HRY after parboiling. Increasing the soaking temperature from 159.8 to 168.8 °F caused an increase in rough rice MC from 43.66% to 46.11%. At a temperature exceeding the gelatinization temperature, the water absorption of rice increases significantly (Bello et al., 2007). Increasing soaking temperature from 159.8 to 163.4°F increased MRY and HRY of the sample. A soaking temperature above 163.4 °F resulted in decreased MRY and HRY. Increasing the steaming duration from 5 to 10 min, before MW treatment, increased the sample MC from 44.15% to 46.71%. The MC then decreased to 44.40% at the 15 min steaming duration. Increasing steaming duration from 5 to 15 min caused slight decreases in MRY and HRY of the sample. Taghinezhad et al. (2015) found MRY increases as steaming duration increases.

Implications of Soaking Temperature and Steaming Duration on Protein Content, Surface Lipid Content and Total Color Difference

Table 2 shows the LS means SLC, protein content, TCD of control samples, and their SD. Increasing soaking temperature from 159.8 to 163.4 °F reduced the sample mean protein content from 6.75% to 6.47%. At 168.8 °F soaking temperature, the average protein content decreased further to 5.92%. Ibukun (2008) found that harsher parboiling treatment resulted in lower protein content of rice. The mean SLC of the sample decreased from 0.89% to 0.34% when the soaking temperature was increased from 159.8 to 168.8 °F. Increasing the soaking temperature from 159.8 to 163.4 °F resulted in a decrease of the sample average TCD from 3.26 to 2.25. At 168.8 °F soaking temperature, the mean TCD increased to 5.39.

The mean protein content of the sample was decreased from 6.56% to 6.49% when steaming duration was increased from 5 to 10 min. At 15 min, the mean protein content decreased to 6.08%. Increasing steaming duration from 5 to 10 min resulted in a decrease in mean TCD and an increase in average SLC. Kimura (1993) reported an increase in rice lightness at a steaming duration of 15 min.

Implications of Microwave Specific Energy, Soaking Temperature and Steam Duration on Physicochemical and Milling Characteristics

Figure 2 shows the statistical responses of the studied parameters and responses. The MRY parameter was removed from the analysis because the variance of the MRY response data was too large and led to statistical insignificance of the entire model. Table 3 shows the effect summary table for the studied responses. The table indicates high statistical significance ($P < 0.05$) for the main effects (MW specific energy, soaking temperature, and steaming duration) and a quadratic effect in the model (soaking temperature * soaking temperature) for FMC response. For HRY, the main effect (soaking temperature and MW specific energy) and quadratic effects (soaking temperature * soaking temperature and MW specific energy * MW specific energy) were highly significant ($P < 0.05$). The main effects of soaking temperature, MW specific energy, and steaming duration were significant for protein content and TCD. However, only the soaking temperature effect was significant for SLC. Quadratic effects (soaking temperature*soaking temperature and MW specific energy *

MW specific energy) were significant for protein content, SLC, and TCD ($P < 0.05$). Table 4 shows the summary of fit table for the FMC, HRY, Protein content, SLC, and TCD parameters. This table shows the R-Square, adjusted R-Square, root mean square error, and *p*-Values for those responses. The R-square error for the FMC response was 0.918359. This means that the fitted model respectively explains 91.84% of the variation in the FMC response. The R-square error for the HRY response was 0.750269. This means that the fitted model respectively explains 75.03% of the variation in the HRY response. R-square error for the protein content, SLC, and TCD responses were 0.755237, 0.758838, and 0.419705, respectively.

Figure 3 shows the contour profiler for the HRY, protein content, SLC, FMC, and TCD. A contour profiler shows plots of response contours for multiple factors at a time. An upper limit for FMC and TCD was set as 19.72% and 4.68%, respectively. A lower limit for HRY, SLC, and protein content were set as 67.81%, 0.74% and 5.82, respectively. The white unshaded area shows the safe operating region for optimal HRY, protein content, SLC, FMC, and TCD. This indicates that the optimized responses for HRY, protein content, SLC, FMC, and TCD exist when parameter (factor) settings for soaking temperature, MW specific energy, and steaming duration are set to 73 °C, 0.29 kWh.[kg-DM]$^{-1}$, and 10 minutes.

Practical Applications

Based on this study, it is recommended that long-grain rice of cultivar Mermentau should be soaked at 163.4 °F, steamed for 10 min, and then treated at MW specific energy of 448.84 BTU.[lb-DM]$^{-1}$ to achieve rough rice FMC of 18.79%. With these treatment parameters, parboiled rough rice had a HRY of 69.33% and desirable physicochemical and sensory properties. It may be necessary to continue the drying process using natural or hot air drying to achieve the safe storage MC range of 14.29% to 15.61%. This study demonstrated the feasibility of using 915 MHz MW heating of high-MC parboiled rough rice to achieve one-pass drying.

Acknowledgments

This study was based upon work that is supported, in part, by the United States Department of Agriculture National Institute of Food and Agriculture Hatch Act Funding; AMTeK Microwaves; the Arkansas Rice Research and Promotion Board; and the University of Arkansas System Division of Agriculture.

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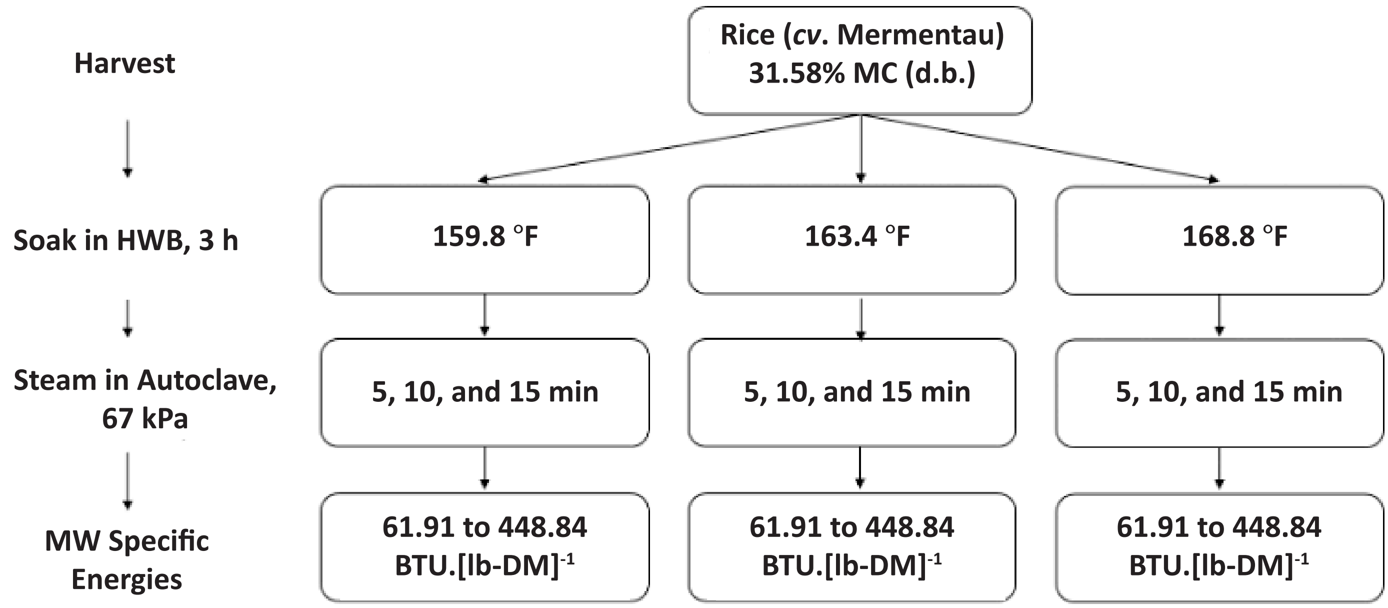

Fig. 1. Overall experimental process flow diagram; cv., HWB, MW, and MC indicates cultivar, hot water bath, microwave, and moisture content, respectively; lb-DM indicates lb of dry matter; d.b. indicates dry basis.

Overall

Column	Main Effect	Total Effect
Soaking Temperature (°F)	0.555	0.624
Specific Energy (BTU.[lb-DM]$^{-1}$)	0.347	0.404
Steaming Duration (min)	0.017	0.039

FMC (% d.b)

Column	Main Effect	Total Effect
Specific Energy (BTU.[lb-DM]$^{-1}$)	0.974	0.993
Soaking Temperature (°F)	0.004	0.013
Steaming Duration (min)	0.001	0.004

SLC (%)

Column	Main Effect	Total Effect
Soaking Temperature (°F)	0.938	0.966
Specific Energy (BTU.[lb-DM]$^{-1}$)	0.014	0.024
Steaming Duration (min)	0.012	0.024

TCD

Column	Main Effect	Total Effect
Specific Energy (BTU.[lb-DM]$^{-1}$)	0.416	0.598
Soaking Temperature (°F)	0.301	0.532
Steaming Duration (min)	0.048	0.113

Protein (%)

Column	Main Effect	Total Effect
Soaking Temperature (°F)	0.702	0.735
Specific Energy (BTU.[lb-DM]$^{-1}$)	0.235	0.269
Steaming Duration (min)	0.01	0.026

HRY (%)

Column	Main Effect	Total Effect
Soaking Temperature (°F)	0.833	0.875
Specific Energy (BTU.[lb-DM]$^{-1}$)	0.097	0.137
Steaming Duration (min)	0.012	0.029

Fig. 2. The variable importance report for the overall, FMC, SLC, TCD, protein content, and HRY responses; FMC = final moisture content, SLC = surface lipid content, TCD = total color difference, HRY = head rice yield, MW = Microwave, d.b. = dry basis, and lb-DM = lb of dry matter.

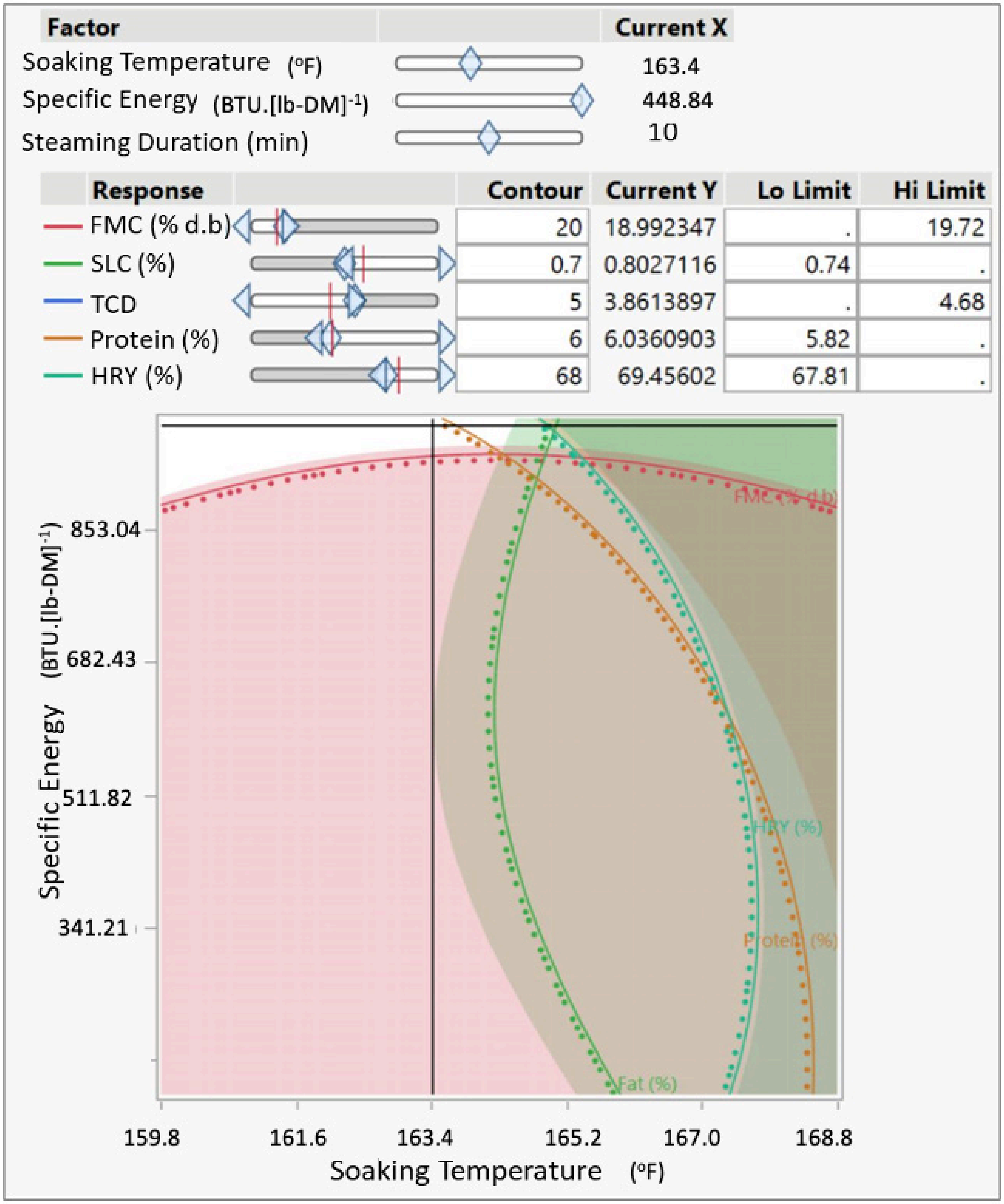

Fig. 3. Contour profiles for head rice yield (HRY), protein content, surface lipid content (SLC), final moisture content (FMC), and total color difference (TCD) responses with parameter settings for soaking temperature, MW specific energy, and steaming duration (kg-DM = kg of dry matter).

World and U.S. Rice Baseline Outlook, 2020–2030

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Abstract

The marketing year 2019 marked the second-highest level of global rice production and a record level of global consumption and stocks. However, global rice trade decreased due to a combination of good production outcomes in key importing countries and the disruptions caused by the COVID pandemic. The price of rice in the international market increased by the end of the 2019 marketing year as COVID pushed some key Asian exporters such as Vietnam and Myanmar to restrict exports. Despite the removal of export restrictions, prices in the international market remain high from most origins well into the still-evolving 2020 marketing year. Over the next decade, the reference price of long-grain rice is projected to increase steadily by 1.3% annually as global consumption grows faster than global production, causing a decline in the stock-to-use ratio. Global trade is projected to grow by 1.8% annually. India and Thailand maintain their dominant roles in global trade as the top rice exporters, followed by Vietnam, Pakistan, Myanmar, and the United States. On the other hand, China, Nigeria, and the Philippines remain the major global rice importers. Over the next decade, the growth in global trade is attributed to the expansion in export shipments from India, Thailand, Vietnam, China, and Myanmar, in tandem with strong import demand from countries in Western Africa and the Middle East.

Introduction

Global rice production has outpaced consumption by more than 9.0 million metric tons (MMT) a year in the three-year period 2017–2019. This means that there is a more supply of rice in the world than it is demanded, which pushed the stock level to more than 35% of the consumption worldwide, the highest level since 2001. Therefore, such a large buildup of global rice stocks has helped curving down the inflationary pressure on rice prices. Asia continues to dominate the global rice market and accounts for 90% of production, 86% of consumption, 95% of stocks, and 83% of global exports in the 2017–2019 period.

Rice remains thinly traded, indicating that most rice is consumed where it is produced. However, international trade is growing and reached 9.0% of global production in the 2017–2019 period, relative to 7.0% a decade ago. India, Thailand, Vietnam, Pakistan, and the U.S. continue dominating rice exports with a combined share of 74.1% of total world trade in 2017–2019. India's sustained rice production growth in the last decade allowed the country to overtake Thailand as the top global rice exporter in the last several years, and that trend strengthened in 2019 as Thailand faced production challenges. Myanmar and Cambodia have become more prominent exporters in the last decade and accounted for 8.8% of global rice exports in 2017–2019.

Prices in the global rice market have strengthened since April 2020, as the coronavirus (COVID-19) pandemic disrupted the global economy in unprecedented ways, and remain strong to date. Except for India, Asian long-grain rice prices remain high in the marketing year 2020. To illustrate, the export price (FOB) for Vietnam's long grain 5% broken averaged $497 per mt in August 2020–February 2021, relative to $346 a year earlier; whereas the price of Thailand's long-grain rice (100% B) averaged $502/mt in August 2020–February 2021 relative to $420 a year earlier. The export price for U.S. long-grain rice (No. 2 4% broken) also increased by almost 10% in the first half of the marketing year 2020 relative to a year earlier (Fig. 1).

Undoubtedly the main development in 2020 has been economic disruption caused by the COVID-19 pandemic. While COVID-19 resulted in price decreases for several commodities such as corn and soybeans (American Farm Bureau Federation, 2020), the price of rice in the international market increased since April 2020, driven in part by the export restrictions imposed by large Asian exporters such as Vietnam and India, and spikes in demand in some regions such as Central America and Brazil as consumers hoarded rice as a risk strategy to cope with the pandemic. Despite the fact that export restrictions have been long lifted and panic hoarding short-lived, rice export prices from most origins remain high well into the 2020 marketing year, as previously discussed. Given its current export competitiveness vis-à-vis other major Asian competitors, India is expected to further consolidate its position as the largest rice exporter in the globe.

Procedures

The baseline estimates presented in this report are generated using the Arkansas Global Rice Model (AGRM), a partial equilibrium, non-spatial, multi-country/regional statistical simulation and econometric framework developed and maintained by the Arkansas Global Rice Economics Program (AGREP) in the University of Arkansas System Division of Agriculture's Department of Agricultural Economics and Agribusiness in Fayetteville, Arkansas. The model covers 70 countries and regions that produce

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and consume rice; and projects rice supply and demand as well as international and domestic rice prices up to 2030.

Most of the details, theoretical structure, and general equations of AGRM can be found in Wailes and Chavez (2011). The historical rice data come from USDA-FAS (2021a, 2021b) and USDA-ERS (2021). Macroeconomic data (e.g., gross domestic product, exchange rate, and population growth) come from IHS Markit provided by the Food and Agricultural Policy Research Institute (FAPRI)-Missouri.[2] The baseline projections are grounded in a series of assumptions as of January 2021 about the general economy, agricultural policies, weather, and technological change. The basic assumptions are a continuation of existing policies, current macroeconomic variables, no new WTO trade reforms, and average normal weather conditions.

Results and Discussion[3]

Over the next decade, the average global long-grain rice price is projected to increase steadily by 1.2% annually, as global rice trade grows 1.8% a year on average over the same period. On average, the long-grain rice international reference price, represented by the FOB price of Thai 100% B rice, increases from \$425 per mt (2017–2019 average) to \$483 per mt in 2030. Over the same period, the average international price for medium-grain rice is projected to remain steadily high, ranging from \$865 per mt (2017–2019 average) to \$873 per mt in 2030 (Table 1). The projected high price of medium-grain rice is consistent with the fact that medium-grain rice exports continue to be limited by water-related production constraints in Australia and Egypt, who are traditional rice suppliers. Egypt has a water-related policy of restricting rice planted areas with penalties for policy breakers, but there are indications that local rice farmers continue to plant rice, as evidenced by the historical data on planted area (USDA-FAS, 2021b). The ongoing water situation could potentially present market opportunities for other medium-grain producers, including the U.S., in markets traditionally served by Australia and Egypt.

Western Hemisphere long-grain rice prices, represented by the U.S. No. 2–4% FOB Gulf price, remain substantially higher than Asian long-grain rice prices in the projected period (2020–2030). The U.S. price margin over Asian long-grain rice (estimated as the difference between the U.S. No. 2–4% and the Thailand 100% B price) averaged \$152 per mt in the marketing years 2017–2019, reaching as high as \$222 in July 2018, but has decreased below \$100 per mt in the first two months of 2021 as Thai export prices remain high due to ongoing production constraints caused by droughts (USDA-ERS, 2021). Over the next decade, the margin is projected to remain steadily close to the average of \$150 per mt (Table 1 and Fig. 2). The convergence of the two prices is not likely since U.S. rice exports benefit greatly from preferential access in its core rice markets (e.g., Mexico, Central America, and Colombia).

Over the next decade, India and China will remain the major players in the global rice economy, given the sheer magnitude of their rice sectors. These two countries are projected to account for 44.8% of total area harvested, 50.7% of total production, 48.6% of total consumption, 29.7% of global exports, 7.4% of global rice imports, and 79.0% of global stocks in the period 2028–2030. On average, the two countries combined are projected to account for 35.1% of the world population over the same period.

Global rice output is projected to continue expanding over the next decade, driven by the increasing adoption of higher-yielding varieties and other improved production technologies—in line with more focused self-sufficiency programs of the major consuming countries in Asia and Africa. World rice production expands by 29.9 MMT over the next decade, equivalent to annual growth of 0.5%, reaching 526.0 MMT in 2030 (Table 2). Most of the production growth is explained by yield improvements, although the world rice harvested area is projected to increase slightly over the same period as the substantial increases in area expected in Nigeria, Thailand, and Tanzania, among others, more than offset the declines in China, Indonesia, Vietnam, and others. India is projected to have the largest growth in production, accounting for around 23% of the production gain in the coming decade. Bangladesh, Thailand, Vietnam, Myanmar, Cambodia, and the Philippines are also expected to increase production significantly over the next decade. In Africa, the largest gains in production are projected for Tanzania and Nigeria. In contrast, rice production in China is projected to decline by 5.3 MMT, and also in Japan, South Korea, Taiwan, and Brazil. Total U.S. rice production is projected to increase by 1.35 MMT over the same period, equivalent to average annual growth of 1.3% (Table 3).

Over the next decade, world rice consumption will continue to be driven by population growth as the global average per-capita rice consumption declines. Rising incomes continue to dampen rice demand in some Asian countries such as Japan, Taiwan, China, and South Korea, where rice is considered an inferior good. Demographic trends also weakened rice demand, as aging populations and increased health-consciousness cause a shift in preferences away from carbohydrates and towards protein-based diets. Over the same period, global rice consumption is projected to increase by 41.8 MMT, reaching nearly 528.5 MMT in 2030, which is equivalent to annual growth of 0.75%. Global average per-capita use of rice is projected to decline by 0.3% a year over the projected period (Table 2).

About 23% of the net growth in global rice consumption is accounted for by India; 16% by the three countries of Bangladesh, the Philippines, and Indonesia combined; and 24% by the Economic Community of West African States (ECOWAS)[4]. The U.S. rice total consumption increases by 626 thousand metric tons (tmt) over the same period, reaching 5.1 MMT in 2030 or an annual growth of 1.3%; which comes primarily from an increase in per-capita consumption.

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[2] FAPRI-Missouri is the lead institution of the research consortium that develops the annual baseline projections. It includes the University of Missouri-Columbia, the University of Nevada-Reno, the University of Arkansas in Fayetteville, Texas A&M University, and Texas Tech University.

[3] Although complete baseline projections for supply and demand variables are generated for all 70 countries/regions covered by AGRM, only selected variables for major countries are discussed in this report due to space consideration.

[4] Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo.

We project that global rice trade will expand by 9.9 MMT or 1.8% annually over the next ten years, reaching 54.6 MMT in 2030 compared to 44.7 MMT for the period 2017–2019 (Table 1). On the exporters' side, the significant investment in production and processing capacity in the Mekong Delta in Vietnam, Cambodia, and Myanmar bodes well for these countries' increasing role as important global rice suppliers over the same period. As low-cost producers, these countries are well-poised geographically to supply the Chinese rice market.

India's competitiveness results from its impressive production record that allows it to secure a reliable excess supply. India's rice exports are projected to surpass 13.5 MMT by 2030, a growth of almost 2.0 MMT over the volume exported in the period 2017–2019. While Thailand's competitiveness has weakened recently primarily due to weather-related issues, we project its export performance will improve and account for almost a third of the expected global export growth over the next decade. Thailand is expected to consolidate as the second-largest rice exporter after India.

For the U.S., total exports over the next decade are expected to increase by 448 tmt, reaching 3.4 MMT in 2030, while imports will increase significantly by 326 tmt, totaling 1.3 MMT in 2030. For reference purposes, detailed U.S. rice supply and use data are presented in English units and in paddy basis (rough rice equivalent) in Table 3.

Over the same period, Myanmar and Cambodia are both expected to assume increasing roles as global rice suppliers. Myanmar's exports are projected to expand from 2.6 MMT a year in 2017–2019 to 3.4 MMT in 2030, supported by yield-based growth in production. Cambodia's exports, on the other hand, are projected to grow from an annual average of 1.3 MMT in the period 2017–2019 to 2.1 MMT in 2030, as both area and yield growth cause production to exceed consumption consistently.

On the import side, China, West Africa, and the Philippines are expected to be the leading rice importers over the next decade. We project that China will remain the largest single rice importer, but imports will grow only marginally over the next decade. Nigeria's rice imports will almost double to 3.4 MMT by 2030, while the Philippines's imports are projected to be almost on par with Nigeria by 2030. In February 2019, the World Trade Organization ruled in favor of a 2016 U.S. complaint that China has consistently exceeded its WTO agricultural subsidy limits. This ruling can have significant implications for the Chinese and global rice markets, including China's rice imports, in the coming years.

China has slowly opened market access to India, Japan, and recently the United States for milled rice. Currently, some countries have bilateral phytosanitary protocols on milled rice with China, including Cambodia, India (both Basmati and Non-Basmati), Japan, Laos, Myanmar, Pakistan, Thailand, Uruguay, Vietnam, Taiwan, and the United States (USDA-FAS, 2019c).

In general, the expansion of imports is associated with a combination of relatively fast population growth and lagging production relative to consumption. For example, Nigeria is expected to expand imports by 6.3% per year, driven by the 2.7% population-led growth in consumption that exceeds the formidable 2.2% annual growth in production. The rest of Western Africa and the Middle East show strong expansion in import demand-based primarily on population growth.

Global rice stocks are projected to grow by 9.4 MMT from their average in 2017–2019 to 2030. However, relative to consumption, global rice stocks are projected to tighten slightly over the next decade, with the stocks-to-use ratio projected to decline from 35.6% on average in the period 2017–2019 to 34.6% in 2030. This trend reflects the relatively faster growth in total global rice consumption relative to the total global rice output gains.

Practical Applications

Understanding the market and policy forces that drive the global rice market is beneficial for Arkansas rice producers and other stakeholders. This is especially true because Arkansas is the top rice-producing state in the U.S., accounting for nearly 42% of the country's rice output (2016–2018 average), and about half of Arkansas' annual rice crop is exported. Market prices received by Arkansas rice producers are primarily determined by the dynamics of the international rice market. This outlook can serve as a baseline reference for further policy scenario analysis, and is intended for use by government agencies and officials, farmers, consumers, agribusinesses, and other stakeholders.

Acknowledgments

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Table 1. Projected changes in world rice total trade by country (in 1,000 metric tons) with U.S. and global prices.

Country	2017–2019 Average	2030	Change	Country	2017–2019 Average	2030	Change
Exporters							
India	11,649	13,594	1,945	EU 28	320	420	100
Thailand	8,039	11,168	3,129	Australia	128	269	141
Vietnam	6,424	7,879	1,455	Peru	95	101	6
Pakistan	4,101	4,248	147	Guinea	93	100	7
United States	2,908	3,356	448	Cote d'Ivoire	77	50	-27
Myanmar	2,583	3,365	782	Egypt	30	100	70
China	2,245	2,645	400	Japan	65	70	5
Cambodia	1,333	2,104	771	Turkey	220	200	-20
Brazil	1,077	1,046	-30	Tanzania	33	30	-3
Uruguay	820	968	148	Venezuela	7	0	-7
Paraguay	714	892	178	Senegal	10	10	0
Guyana	455	671	216	Sri Lanka	6	5	-1
Argentina	368	470	102	Laos	-101	381	481
				Rest of world	977	479	-498
Total Exports					**44,677**	**54,621**	**9,945**
Importers							
China	3,767	4,034	267	Canada	405	456	50
Nigeria	1,733	3,377	1,644	Sierra Leone	360	291	-69
ECOWAS 7[a]	2,155	3,566	1,411	Egypt	399	250	-149
Philippines	2,450	3,352	902	Liberia	343	352	9
EU 28	2,199	2,441	241	Sri Lanka	178	225	47
Cote d'Ivoire	1,257	2,300	1,043	Hong Kong	324	402	78
Saudi Arabia	1,405	1,804	399	Peru	314	607	293
Iran	1,233	2,005	772	Singapore	319	320	0
Bangladesh	1,207	-329	-1,535	Turkey	486	343	-143
Iraq	1,178	1,459	281	Tanzania	233	288	55
Senegal	1,117	1,802	685	Thailand	250	250	0
South Africa	1,015	1,102	87	Mali	277	1153	877
Indonesia	1,167	1,406	239	Australia	231	171	-59
Malaysia	983	845	-138	Chile	162	189	26
United States	993	1,319	326	Costa Rica	141	177	36
Mexico	787	934	147	Colombia	186	314	128
Ghana	847	1,344	498	Honduras	131	178	47
Guinea	673	735	62	Uganda	63	174	111
Japan	667	682	15	Taiwan	106	126	20
Brazil	720	572	-147	Guatemala	110	151	41
Kenya	604	1,340	736	Nicaragua	93	81	-12
Mozambique	607	1,194	587	Panama	117	112	-5
Cameroon	598	973	375	Brunei	35	59	24
Cuba	450	512	63	Rwanda	40	158	118
Haiti	501	587	86	Dominican Republic	26	108	81
Vietnam	467	400	-67	Malawi	15	53	38
Venezuela	480	633	153	Zambia	10	53	43
South Korea	381	409	28	Pakistan	0	0	0
Madagascar	487	703	215	Paraguay	2	2	0
				Rest of world	7194	6076	-1118
Total Imports					**44,677**	**54,621**	**9,945**
Prices (US$/metric ton)							
Long-grain International Rice Reference Price (Thailand 100% B)					425	483	59
U.S. No. 2 long grain FOB[b] Gulf Ports					592	633	41
U.S. No. 1 medium grain FOB California					865	873	8

[a] Includes the following seven members of the Economic Community of West African States (Benin, Burkina, Gambia, Guinea-Bissau, Niger, Togo, and Cape Verde).

[b] FOB = free on board.

Table 2. Projected world rice supply and utilization (in 1,000 metric tons) and macroeconomic data.

Variable	2017–2019 Average	2030	Change
Area Harvested (1000 ha)	161,910	162,569	659
Yield (kg/ha)	3.1	3.2	0.2
Production	496,051	525,967	29,916
Beginning Stocks	163,921	185,290	21,369
Domestic Supply	659,972	711,257	51,285
Consumption	486,653	528,497	41,844
Ending Stocks	173,148	182,577	9,428
Domestic Use	659,801	711,073	51,272
Total Trade	44,677	54,621	9,945
Stocks-to-Use Ratio (%)	35.6	34.5	-1.0
Annual population growth (%)	1.1	0.8	-0.3
Annual real GDP[a] growth (%)	1.9	2.0	0.0

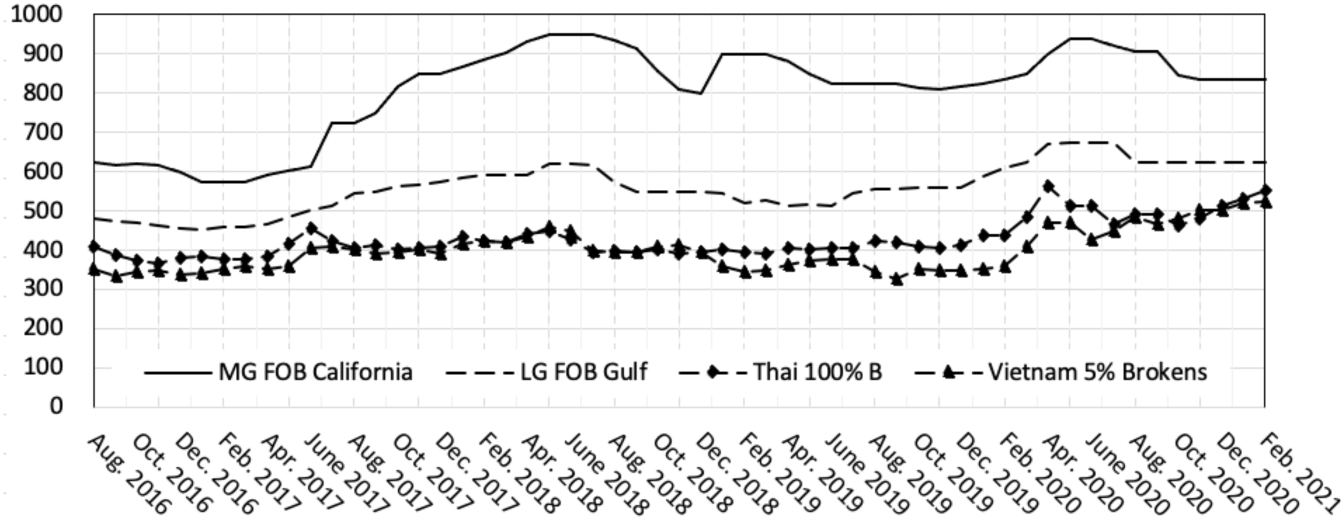
[a] GDP = gross domestic product.

Table 3. United States rice supply and utilization (in paddy basis, million hundredweight unless specified otherwise), prices, and macroeconomic data.

Variable	2017–2019 Average	2030	Change
Yield (lb/ac, paddy basis)	7620.2	8079.5	459.4
Total Harvested Area (million ac)	2565.3	2792.6	227.3
Supply	267.1	311.0	44.0
Production	195.7	225.6	29.9
Beginning Stocks	40.1	43.8	3.7
Imports	31.3	41.6	10.3
Domestic Use	141.2	160.9	19.7
Food	116.7	127.2	10.5
Seed	2.2	2.3	0.1
Brewing	19.1	20.5	1.4
Residual	3.1	10.9	7.8
Exports	91.6	105.7	14.1
Total Use	232.8	266.6	33.8
Ending Stocks	34.3	44.4	10.1
Stocks-to-Use Ratio	14.8	16.7	1.9
	Market Prices (US$/cwt)		
Loan Rate	6.50	7.00	0.50
Season Average Farm Price	13.00	14.07	1.07
Long-Grain Farm Price	11.43	13.02	1.59
Medium-Grain Farm Price	17.77	17.88	0.11
Japonica Farm Price	20.60	19.99	-0.61
Southern Medium-Grain Farm Price	11.87	13.18	1.31
	Reference Prices (US$/cwt)		
Long-Grain Farm Price	14.0	14.0	0.0
Southern Medium-Grain Farm Price	14.0	14.0	0.0
Japonica	16.1	16.1	0.0
Long-Grain Export Price, FOB[a] Houston (U.S. No. 2)	26.2	28.0	1.9
Medium-Grain Price, FOB[a] CA (U.S. No. 2)	39.2	39.6	0.4
Average World Price (US$/cwt)	9.0	10.9	1.9
Per Capita Use (lb/capita)	43.2	46.5	3.3
Population growth (%)	0.5	0.5	0.0
Real GDP[b] Growth (%)	2.5	2.3	-0.2

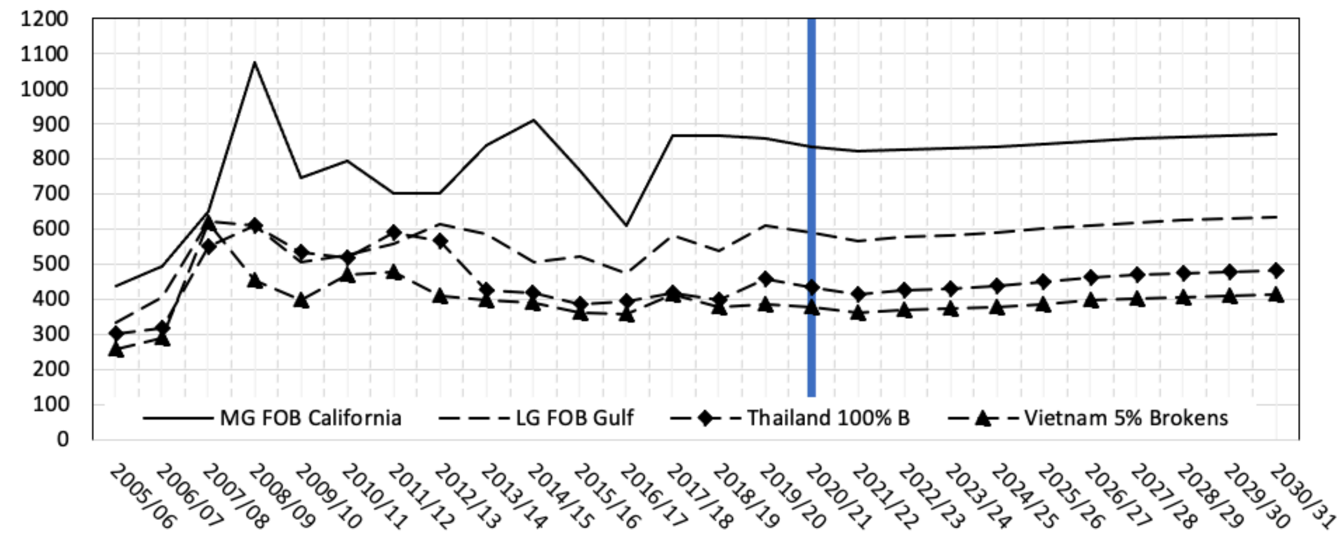
[a] FOB = free on board.

[b] GDP = gross domestic product.



Source: USDA-ERS Rice Outlook, February 2021

Fig. 1. Monthly Historical U.S. and Asian milled rice prices, US$ per metric ton, August 2016–February 2021.



Source: USDA-ERS Rice Outlook, January 2021

Fig. 2. Annual Historical and Projected U.S. and Asian milled rice prices, US$ per metric ton, 2005-2031. The vertical blue line depicts the start of the projected period.

Estimating the Impact of Rice Planting Date and Cultivar Type on Rice Economic Returns in Arkansas

T.K. Gautam,[1] K.B. Watkins,[1] and J.T. Hardke[2]

Abstract

Planting rice too early as well as too late may result in significant yield and milling quality loss. Profit maximizing producers seek appropriate planting dates to optimize returns. Earlier studies primarily focused on the impacts of planting dates on public pure-line rice cultivars. However, rice producers currently have several different rice cultivar types to choose from, ranging from public pure-lines, proprietary herbicide-tolerant cultivars, proprietary hybrids, and proprietary herbicide-tolerant hybrid combinations. Furthermore, the effects of planting date on economic returns have not been evaluated in previous studies. The objective of this study is to evaluate the impact of rice planting date on gross returns for five rice cultivar types grown in Arkansas using data from annual University of Arkansas System Division of Agriculture Degree-Day 50 (DD50) studies for the period 2001–2019 and using pooled Ordinary Least Squares (OLS) estimation. Findings indicate rice planting dates significantly impact rice gross economic returns. Early planting in the latter part of March or the first two weeks of April tends to generate larger gross economic returns relative to rice planting at later dates. Findings also indicate that planting date impacts on rice gross returns vary by rice cultivar type.

Introduction

Planting rice in an appropriate period of time is critical for profitable rice production. Planting rice too early as well as too late may result in significant yield and milling quality loss. The planting decision depends not only on the planting date but also on the type of rice cultivar planted. The planting decision is also strongly impacted by weather. Rice growers may not be able to plant at a desirable date as the weather becomes a major factor. Arkansas rice planting in 2019 demonstrates this. Rice plantings throughout most of 2019 were significantly delayed relative to the five-year state average due to excessive precipitation and flooding occurring throughout the 2019 growing season (Fig. 1).

Studies evaluating planting date impacts on rice are based on an agronomic perspective. Sha and Linscombe (2007) evaluated the impacts of planting date on grain yield and milling quality of Clearfield rice. Slaton et al. (2003) evaluated the planting date effect on rice yields in Arkansas and Louisiana. Both Blanche and Linscombe (2009) and Gravois and Helms (1998) evaluated the impacts of planting date and cultivar on rice grain yields and milling quality. These studies did not incorporate as many cultivar types as the present study. Also, the earlier studies focused on the two key components affecting rice profitability (grain yields, milling yields) but did not examine rice planting date impacts on monetary returns, which represent a combination of both key components. The main objective of this study is to evaluate the impact of rice planting date and cultivar type on rice gross returns.

Procedures

Data for this study come from annual Degree-Day 50 (DD50) rice cultivar thermal unit threshold studies conducted by the University of Arkansas System Division of Agriculture to update the DD50 computer management aid used by Arkansas rice producers (Clayton et al., 2020). Grain yields, whole kernel milling yields, total milling yields, and days from emergence to 50% heading were collected by planting date, cultivar, and year from these annual DD50 studies for the period 2001 through 2019.

Gross returns were calculated by rice cultivar, planting date, and year as the product of rice grain yields and milling adjusted rice prices. Milling adjusted rice prices were calculated based on head rice and total rice milling yields recorded in the DD50 studies, five-year average U.S. long- and medium-grain prices ($4.96/bu. and $5.12/bu., respectively) obtained from the USDA National Agricultural Statistics Service (USDA-NASS, 2021) and five-year average long- and medium-grain loan values for whole and broken kernels ($4.62/bu. and $2.96/bu. for long-grain; $4.39/bu. and $2.96/bu. for medium-grain) obtained from the USDA Farm Service Agency (USDA-FSA, 2021) for the period 2015–2019. Milling adjusted long- and medium-grain prices were calculated based on standard milling yields for each grain type (55/70 for long-grain; 58/69 for medium-grain). Five-year average prices were used to standardize all milling adjusted rice prices to contemporary average 2015–2019 values.

The study uses a pooled Ordinary Least Squares (OLS) estimator and panel data to estimate the impact of rice planting date on rice gross returns in Arkansas. The model is specified as follows:

$$y_{it} = \vartheta_0 + X_{it}'\beta + \varepsilon_{it}$$

Here, y_{it} is the vector of dependent variable (rice gross returns), i represents crop fields (i = 1,2,…n), t represents year, X is the vector of explanatory variables (days from rice emergence to 50% heading, planting dates), and ε_{it} is the error term. The model

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relaxes the assumption that zero conditional mean error holds for the idiosyncratic error. It ignores the correlation between the combined error and the explanatory variables. Major problems arise from the heteroskedasticity and possible violation of zero conditional mean errors. Both problems arise out of ignoring the unmeasured heterogeneity inherent in unobserved fixed effects. In this situation, an instrumental variable (IV) or other alternative approach is desirable to account for these problems. However, given the data type we are dealing with, a pooled OLS seems to be feasible as a least square dummy variable estimator and could be a better alternative to the IV method, according to Wooldridge (2010). We account for these major model issues by including yearly dummies and employing clustered estimation.

Gross returns by rice cultivar were grouped into five rice cultivar types: long-grain pure-lines (LGPL), medium-grain pure-lines (MGPL), herbicide-tolerant cultivars (HT), hybrids (HYB), and herbicide-tolerant hybrid combinations (HTHYB). Rice planting dates were grouped into six different designations: PD1 (planting dates in later March); PD2 (1–15 April), PD3 (16–30 April), PD4 (1–25 May), PD5 (26 May–9 June), and PD6 (planting dates beyond 9 June). These PD designations range from very early (planting dates in later March, or PD1) to very late (beyond 9 June, or PD6). Planting dates were partitioned based on RMA rice crop insurance planting date rules. For example, rice planted in March (PD1) is not eligible for crop insurance, 1 April (the beginning date for PD2) represents the earliest planting date allowed by RMA to ensure a rice crop; 25 May (the end date for PD4) represents the Final Planting Date for rice for which a rice producer can receive the full production guarantee for an insured crop; 16 May–9 June (PD5) represents the late planting period, with the production guarantee for each acre planted reduced by 1 percent each day up to 9 June, and beyond 9 June (PD6) represents very late rice planting dates for which the rice crop cannot be insured. Rice can be planted extremely late in growing seasons experiencing frequent and heavy precipitation. From a historical perspective, 20% of rice plantings in 2019 occurred after the 25 May Final Planting Date, and 5% of rice plantings in 2019 occurring beyond 9 June due to heavy precipitation and flooding that occurred throughout much of the 2019 growing season (Fig. 1).

Results and Discussion

Summary statistics and descriptions of variables used in the study are presented in Table 1. The average yield is highest for HYB, followed by HTHYB, MGPL, LGPL, and HT, respectively. The average gross returns show that HYB and HTHYB generate nearly equal average gross returns ($1038 per acre), followed by MG, LGPL, and HT rice. The average number of days from emergence to 50% heading ranges from 81 days for HYB and HTHYB rice to 84 days for LGPL and MGPL, indicating the hybrids tend to mature slightly faster relative to pure-line rice cultivars.

Results of the pooled OLS regression are presented in Table 2. All coefficients for Days to 50% heading are not significant, indicating little impact of this cultivar maturity measure on rice gross returns across all five rice cultivar types. Planting Dates (PDs) 1 through 5 are presented in Table 2, with PD6 (planting beyond June 9) being the base category in the pooled OLS estimation. Coefficients for PD1 through PD5 are therefore compared relative to PD6, the latest planting period designation in the study. All PD coefficients are statistically significant at either the 1% or the 5% significance levels, implying planting rice at different PDs has a large and significant impact on rice economic returns.

PD coefficients are the largest in magnitude for PD1 (planting in March) across all rice cultivar types and progressively become smaller at later PDs. These results indicate early rice plantings generally result in the greatest economic return for rice producers across all rice cultivar types. However, the magnitude of coefficients for a given PD differs by rice cultivar type. For example, estimated coefficients for LGPL and HT cultivar types planted in March (PD1) generate over 40% more gross returns relative to planting beyond 9 June (PD6). Cultivar types HYB and HTHYB planted in March generate approximately 36% more gross returns, while the MGPL cultivar type planted in March generates over 22% more gross returns relative to planting beyond 9 June.

For all five rice cultivar types, May and June planting dates are the least favorable relative to March and April planting dates. These results should come as no surprise, as rice producers would only plant rice at these late planting dates because the weather did not permit them to plant earlier. Since rice acres planted before 1 April are not eligible for crop insurance and since March PD coefficients in our study are larger in magnitude relative to coefficients for later PDs, we conducted F-tests to determine if March and early April PD coefficients were statistically different for each rice cultivar type. For MGPL and HTHYB rice cultivar types, gross return coefficients corresponding to PD1 (March) and PD2 (1–15 April) are not significantly different as we fail to reject the null hypothesis of equal coefficients. In the case of rice cultivar types LGPL, HT, and HTHYB, the gross return coefficients associated with PD1 and PD2 are significantly different, as evidenced by the rejection of the null hypothesis. Thus, growers need to evaluate the comparative potential benefits from crop insurance and economic returns when making decisions to plant in either March or early April.

Practical Applications

The findings of this study show that rice planting dates significantly impact rice gross economic returns. Early planting in the latter part of March or the first two weeks of April tends to generate larger gross economic returns relative to rice planting at later dates. Although planting rice in March and early April tends to generate larger gross economic returns for rice based on our study, historical rice planting data in Arkansas indicates few rice acres are planted in these time frames. Very little rice is planted in March, and 30% of rice acres are planted in the first two weeks of April based on the 5-year state average rice planting data presented in Fig 1. Weather and crop insurance rules tend to dictate how early rice may be planted in the state. Cold, wet weather in early spring limits early planting activity in many years and locations, while rice acres can be covered by crop insurance only if planted on or after 1 April. We also find that planting date impacts on rice gross returns vary by rice cultivar type. March planting dates produce significantly larger gross returns relative to early April planting dates for long-grain pure-lines, herbicide-tolerant cultivars, and hybrids, while gross returns for rice planted in March or early April are not significantly different for medium-grain pure-lines and herbicide-tolerant hybrids.

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Table 1. Summary statistics and description of variables used in the analysis.

Variable	Cultivar types	Obs.	Mean	Minimum	Maximum
Rice Grain Yield (bu./ac)	LGPL[a]	83	168.24	75.83	234.00
	MGPL	83	175.70	85.70	262.00
	HT	83	158.90	60.60	228.71
	HYB	79	206.10	72.50	281.00
	HTHYB	66	203.24	77.00	270.33
Rice Gross Returns ($/ac)	LGPL	80	859.77	400.38	1167.10
	MGPL	80	1002.15	454.23	1529.32
	HT	80	822.65	312.76	1214.77
	HYB	76	1038.50	378.54	1404.23
	HTHYB	65	1037.83	399.58	1428.63
Days from emergence to 50% heading	LGPL	79	84.30	70.63	115.63
	MGPL	79	83.94	71.00	110.33
	HT	79	83.83	68.00	110.50
	HYB	75	81.42	63.50	104.50
	HTHYB	61	81.46	66.00	108.33

[a] Abbreviations: LGPL, MGPL, HT, HYB, and HTHYB represent long grain pure-line, medium-grain pure-line, herbicide tolerant, hybrid, and herbicide tolerant hybrid types, respectively.

Table 2. Estimated gross return by four cultivar types using the pooled ordinary least squares estimator.

	Cultivar types				
Variable description[a]	**LGPL[b]**	**MGPL**	**HT**	**HYB**	**HTHYB**
Days to 50% heading[c]	-0.114	0.337	0.105	-0.186	-0.075
	(0.1150)[d]	(0.2450)	(0.2450)	(0.2460)	(0.2010)
PD1 (March)[e]	0.404***[f]	0.221**	0.402***	0.353***	0.361***
	(0.0251)	(0.0556)	(0.0510)	(0.0602)	(0.0431)
PD2 (April 1–15)	0.324***	0.178***	0.317***	0.279***	0.355***
	(0.0145)	(0.0319)	(0.0319)	(0.0401)	(0.0251)
PD3 (April 16–30)	0.292***	0.117***	0.292***	0.247***	0.280***
	(0.0122)	(0.0254)	(0.0242)	(0.0320)	(0.0212)
PD4 (May 1–25)	0.0903***	0.024**	0.043***	0.088***	0.155***
	(0.0042)	(0.0073)	(0.0075)	(0.0138)	(0.0107)
PD5 (May 26–June 9)	0.093***	-0.121***	0.101***	0.107***	0.118***
	(9.23e-05)	(0.0017)	(0.0023)	(0.0055)	(0.0005)
Constant	7.015***	5.306***	6.009***	7.551***	7.025***
	(0.4990)	(1.063)	(1.064)	(1.054)	(0.8650)
Observations	76	76	76	72	61

[a] All variables except planting dates are in natural logarithm.

[b] Abbreviations LGPL, MGPL, HT, HYB, and HTHYB represent long-grain pure-line, medium-grain pure-line, herbicide tolerant, hybrid, and herbicide tolerant hybrid types, respectively.

[d] Days from emergence to 50% heading.

[d] Robust standard errors in parentheses.

[e] PD = Planting Date dummy variable designations, with PD1 (later part of March) being earliest and PD6 (planting beyond June 9) being the latest. PD6 is considered the base category in the model.

[f] Asterisks ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

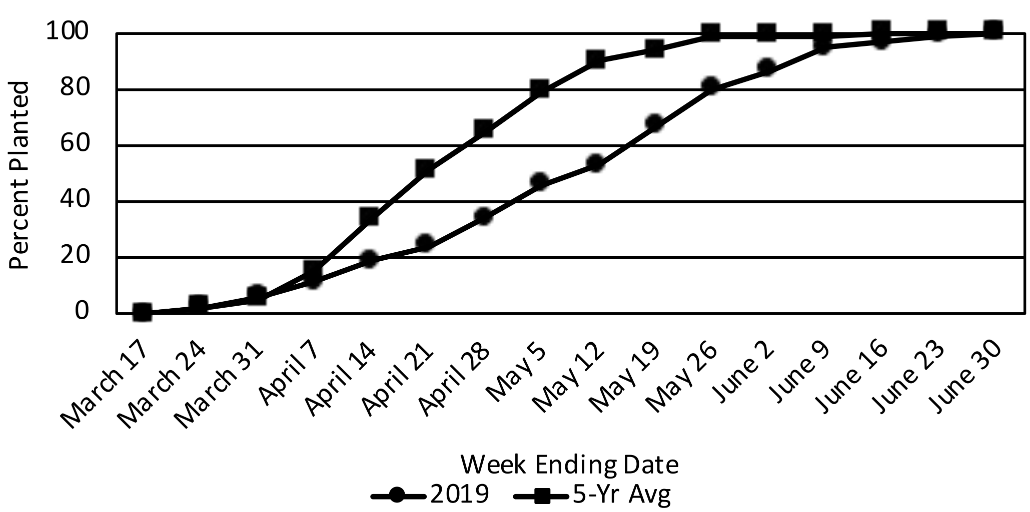

Fig. 1. Arkansas rice planting progress during 2019 compared to the five-year state average (USDA-NASS, 2021).

Rice Enterprise Budgets and Production Economic Analysis

B.J. Watkins[1]

Abstract

Crop enterprise budgets are developed that are flexible for representing alternative production practices of Arkansas producers. Interactive budget programs apply methods that are consistent over all field crops. Production practices for base budgets represent the University of Arkansas System Division of Agriculture's Cooperative Extension recommendations from Crop Specialists and from the Rice Research Verification Program. Unique budgets can be customized by users based on either Extension recommendations or information directly from on-farm decisions and production practices. The budget program is utilized to conduct an economic analysis of field data in the Rice Research Verification Program. The crop enterprise budgets are designed to evaluate the solvency of various field activities associated with crop production. Costs and returns analysis with budgets are extended by production economics analysis to investigate factors impacting farm profitability.

Introduction

Simultaneously, volatile commodity prices and steady input prices present challenges for producers to maintain profitability. Producers need the means to calculate costs and returns of production alternatives to estimate potential profitability. The objective of this research is to develop an interactive computational program that will enable stakeholders of the Arkansas rice industry to evaluate production methods for comparative costs and returns.

Procedures

Methods employed for developing crop enterprise budgets include input prices that are estimated directly from information available from suppliers and other sources, as well as costs estimated from engineering formulas developed by the American Society of Agricultural and Biological Engineers. Input costs for fertilizers and chemicals are estimated by applying prices to typical input rates. Input prices, custom hire rates, and fees are estimated with information from industry contacts. Methods of estimating these operating expenses presented in crop enterprise budgets are identical to producers obtaining cost information for their specific farms. These prices, however fail to take into account discounts from buying products in bulk, preordering, and other promotions that may be available at the point of purchase.

Ownership costs and repair expenses for machinery are estimated by applying engineering formulas to representative prices of new equipment (Givan, 1991; Lazarus and Selly, 2002). Repair expenses in crop enterprise budgets should be regarded as value estimates of full-service repairs. Repairs and maintenance performed by hired farm labor will be partially realized as wages paid to employees. Machinery performance rates of field activities utilized for machinery costs are used to estimate the time requirements of an activity, which is applied to an hourly wage rate for determining labor costs (USDA-NASS, 2019). Labor costs in crop enterprise budgets represent time devoted, and recently labor costs associated with irrigation have been added to the rice budgets.

Ownership costs of machinery are determined by the capital recovery method, which determines the amount of money that should be set aside each year to replace the value of equipment used in production (Kay and Edwards, 1999). This measure differs from typical depreciation methods, as well as actual cash expenses for machinery. Amortization factors applied for capital recovery estimation coincide with prevailing long-term interest rates (Edwards, 2005). Interest rates in this report are from Arkansas lenders as reported in October 2019. Representative prices for machinery and equipment are based on contacts with Arkansas dealers, industry list prices, and reference sources (Deere & Company 2019; MSU 2019). Revenue in crop enterprise budgets is the product of expected yields from following Extension practices under optimal growing conditions and utilizing an average of prices received data published during the harvest period.

Results and Discussion

The Department of Agricultural Economics and Agribusiness (AEAB) and Agriculture and Natural Resources (ANR) together develop annual crop enterprise budgets to assist Arkansas producers and other agricultural stakeholders in evaluating expected costs and returns for the upcoming field crop production year. Production methods analyzed represent typical field activities as determined by consultations with farmers, county agents, and information from Crop Research Verification Program Coordinators in the Department of Crop, Soil, and Environmental Sciences. Actual production practices vary greatly among individual farms due to management preferences and between production years due to climatic conditions. Analyses are for generalized circumstances with a focus on consistent and coordinated application of budget methods for all field crops. This approach results in meaningful costs and returns comparisons for decision-making related to acreage allocations among field crops. Results should be regarded only as a guide and a basis for individual farmers developing budgets for their production practices, soil types, and other unique circumstances.

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Table 1 provides an example of the 2020 crop enterprise budget for Arkansas dry-seeded, delayed-flood conventional rice. Costs are presented on a per-acre basis and with an assumed yield of 170 bushels at a $4.80/bushel price received. Program flexibility allows users to change total acres, as well as numerous variables to represent unique farm situations. Expected returns to total specified expenses are $72.14/acre for conventional rice systems in Arkansas. Table 2 is an example of a Hybrid rice budget. For hybrid rice systems in Arkansas, expected returns to total specified expenses are $88.85/acre. The budget program includes similar capabilities for Clearfield, Clearfield hybrid, and water-seeded rice production. Since then, FullPage system budgets have been added.

Practical Applications

The crop enterprise budget program has a state-level component that develops base budgets. County extension faculty can utilize base budgets as a guide to developing budgets that are specific to their respective counties, as well as customized budgets for individual producers. A county delivery system for crop enterprise budgets is consistent with the mission and organizational structure of the Arkansas Cooperative Extension Service.

The benefits provided by the economic analysis of alternative rice production methods provide a significant reduction in financial risk faced by producers. Arkansas producers have the capability with the budget program to develop economic analyses of their individual production activities. Unique crop enterprise budgets developed for individual farms are useful for determining credit requirements. Flexible crop enterprise budgets are useful for planning that determines production methods with the greatest potential for financial success. Flexible budgets enable farm financial outlooks to be revised during the production season as inputs, input prices, yields, and commodity prices change. Incorporating changing information and circumstances into budget analysis assists producers and lenders in making decisions that manage financial risks inherent in agricultural production.

Acknowledgments

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Table 1. 2020 Rice Enterprise Budget, conventional seed.

Crop Value	**Grower %**	**Unit**	**Yield[a]**	**Price/Unit**	**Revenue**
Crop Value, Enter Expected Farm Yield & Price	100%	bu.	170.00	4.80	816.00
Operating Expenses		**Unit**	**Quantity**	**Price/Unit[b]**	**Costs**
Seed, Includes Applicable Fees	100%	acre (ac)	1	36.72	36.72
Nitrogen 100%	100%	lb	152	0.38	57.75
Phosphate (0-46-0)	100%	lb	87	0.19	16.75
Potash (0-0-60)	100%	lb	100	0.17	17.25
Ammonium Sulfate (21-0-0-24)	100%	lb	0	0.16	0.00
Boron 15%	100%	lb	0	0.60	0.00
Agrotain, Other Nutrients	100%	ac	1	9.09	9.09
Herbicide	100%	ac	1	111.92	111.92
Insecticide	100%	ac	1	1.75	1.75
Fungicide	100%	ac	1	25.43	25.43
Other Chemical	100%	ac	1	0.00	0.00
Other Chemical	100%	ac	1	0.00	0.00
Custom Chemical & Fertilizer Applications					
Ground Application: Fertilizer & Chemical	100%	ac	0	7.50	0.00
Air Application: Fertilizer & Chemical	100%	ac	5	8.00	40.00
Air Application: lb	100%	lb	330	0.080	26.40
Other Custom Hire, Air Seeding	100%	ac	0	8.00	0.00
Machinery and Equipment					
Diesel Fuel, Pre-Post Harvest	100%	gal.	4.363	2.50	10.91
Repairs and Maintenance, Pre-Post Harvest	100%	ac	1	6.96	6.96
Diesel Fuel, Harvest	100%	gal.	3.082	2.50	7.70
Repairs and Maintenance, Harvest	100%	ac	1	11.59	11.59
Irrigation Energy Cost	100%	ac-in.	30	2.95	88.58
Irrigation System Repairs & Maintenance		ac-in.	30	0.24	7.20
Supplies (ex. polypipe)	100%	ac	1	0.00	0.00
Levee Gates	100%	ac	1	0.70	0.70
Labor, Field Activities	100%	hours	0.909	11.33	10.30
Scouting/Consultant Fee	100%	ac	1	8.00	8.00
Other Expenses	100%	ac	1	0.00	0.00
Crop Insurance	100%	ac	1	10.00	10.00
Interest, Annual Rate Applied for 6 Months	100%	rate %	5.50	505.00	13.89
Custom Harvest	100%	ac	0	0.00	0.00
Post-Harvest Expenses					
Drying	100%	bu.	170.00	0.40	68.00
Hauling	100%	bu.	170.00	0.19	32.30
Check Off, Boards	100%	bu.	170.00	0.01	2.30
Cash Land Rent		ac	1	0.00	0.00
Total Operating Expenses					**$621.48**
Returns to Operating Expenses					**$194.52**
Capital Recovery & Fixed Costs					
Machinery and Equipment		ac	1	77.01	77.01
Irrigation Equipment		ac	1	41.52	41.52
Farm Overhead[c]		ac	1	3.85	3.85
Total Capital Recovery & Fixed Costs					**$122.38**
Total Specified Expenses					**$743.86**
Net Returns					**$72.14**

[a] Yield and inputs are based on Extension research data. Enter expected farm yield and inputs.
[b] All price estimates do NOT include rebates, bulk deals, or discounts available through suppliers.
[c] Estimate based on machinery and equipment.

Table 2. 2020 Rice Enterprise Budget, hybrid seed.

Crop Value	**Grower %**	**Unit**	**Yield[a]**	**Price/Unit**	**Revenue**
Crop Value, Enter Expected Farm Yield & Price	100%	bu.	190.00	4.80	912.00
Operating Expenses		**Unit**	**Quantity**	**Price/Unit[b]**	**Costs**
Seed, Includes Applicable Fees	100%	ac	1	136.39	136.39
Nitrogen 100%	100%	lb	152	0.38	57.75
Phosphate (0-46-0)	100%	lb	87	0.19	16.75
Potash (0-0-60)	100%	lb	100	0.17	17.25
Ammonium Sulfate (21-0-0-24)	100%	lb	0	0.16	0.00
Boron 15%	100%	lb	0	0.60	0.00
Agrotain, Other Nutrients	100%	ac	1	10.27	10.27
Herbicide	100%	ac	1	111.92	111.92
Insecticide	100%	ac	1	1.75	1.75
Fungicide	100%	ac	1	6.00	6.00
Other Chemical	100%	ac	1	0.00	0.00
Other Chemical	100%	ac	1	0.00	0.00
Custom Chemical & Fertilizer Applications					
Ground Application: Fertilizer & Chemical	100%	ac	0	7.50	0.00
Air Application: Fertilizer & Chemical	100%	ac	3	8.00	24.00
Air Application: Lbs.	100%	lb	330	0.080	26.40
Other Custom Hire, Air Seeding	100%	ac	0	8.00	0.00
Machinery and Equipment					
Diesel Fuel, Pre-Post Harvest	100%	gal.	4.363	2.50	10.91
Repairs and Maintenance, Pre-Post Harvest	100%	ac	1	6.96	6.96
Diesel Fuel, Harvest	100%	gal.	3.082	2.50	7.70
Repairs and Maintenance, Harvest	100%	ac	1	11.59	11.59
Irrigation Energy Cost	100%	ac-in.	30	2.95	88.58
Irrigation System Repairs & Maintenance		ac-in.	30	0.24	7.20
Supplies (ex. polypipe)	100%	ac	1	0.00	0.00
Levee Gates	100%	ac	1	0.70	0.70
Labor, Field Activities	100%	hours	0.909	11.33	10.30
Scouting/Consultant Fee	100%	ac	1	8.00	8.00
Other Expenses	100%	ac	1	0.00	0.00
Crop Insurance	100%	ac	1	10.00	10.00
Interest, Annual Rate Applied for 6 Months	100%	rate %	5.50	570.42	15.69
Custom Harvest	100%	ac	0	0.00	0.00
Post-Harvest Expenses					
Drying	100%	bu.	190.00	0.40	76.00
Hauling	100%	bu.	190.00	0.19	36.10
Check Off, Boards	100%	bu.	190.00	0.01	2.57
Cash Land Rent		ac	1	0.00	0.00
Total Operating Expenses					**$700.77**
Returns to Operating Expenses					**$211.23**
Capital Recovery & Fixed Costs					
Machinery and Equipment		ac	1	77.01	77.01
Irrigation Equipment		ac	1	41.52	41.52
Farm Overhead[c]		ac	1	3.85	3.85
Total Capital Recovery & Fixed Costs					**$122.38**
Total Specified Expenses					**$823.15**
Net Returns					**$88.85**

[a] Yield and inputs are based on Extension research data. Enter expected farm yield and inputs.
[b] All price estimates do NOT include rebates, bulk deals, or discounts available through suppliers.
[c] Estimate based on machinery and equipment.

An Overview of Rice Prevented Planting Acres in Arkansas, 2011 to 2020

K.B. Watkins[1] and T.K. Gautam[1]

Abstract

Rice prevented-planting acres in Arkansas reached a record high of 512 thousand acres in 2019 due to flooding and excessive precipitation occurring throughout the growing season. The 2020 crop year recorded the second largest number of rice prevented-planting acres (373 thousand) due to frequent precipitation in the spring months and low or mild temperatures in the spring and summer months, slowing field drying. This study uses data from the USDA Farm Service Agency Crop Acreage Data website to evaluate changes in Arkansas rice prevented-planting acres during the years 2011 through 2020. Rice prevented-planting acres are evaluated for the entire state and also by region to determine how rice prevented-planting acres varied from year to year and to determine where most of these acres have been concentrated. Results reveal large numbers of rice prevented-planting acres in six of the ten years examined, with three years (2019, 2020, and 2013) resulting in historic records for the state. The majority of rice prevented-planting acres each year were located in northeastern Arkansas.

Introduction

Prevented planting is defined as the inability to plant the intended acreage of an insured crop with proper equipment by the final planting date or during the late planting period for the crop because of a natural disaster (USDA-FSA, 2018; USDA-RMA, 2020). For rice in Arkansas, the natural disaster leading to the inability to plant the crop is typically a flood or excessive precipitation occurring during the insurance period. Rice prevented-planting acres in Arkansas vary from year to year due to weather. However, rice prevented-planting acreage reached record highs of 512 thousand acres during the 2019 growing season and 373 thousand acres during the 2020 growing season (USDA-FSA, 2021). The objectives of this study are to compare rice prevented-planting acres in Arkansas for the period 2011–2020 and determine where these acres were mostly concentrated within the state.

Procedures

This study uses data from the USDA-FSA Crop Acreage Data website for the years 2011 through 2020 (USDA-FSA, 2021). Data on rice planted acres, harvested acres, and prevented-planting acres are collected for the entire state over the ten-year period. Rice-planted and prevented-planting acres are then evaluated on a regional basis to determine where most planted and prevented planting acres occur each year in Arkansas. Regional designations in this study follow the Arkansas statistical reporting districts used by the USDA National Agricultural Statistics Service (USDA-NASS, 2021). These statistical reporting districts are defined as follows: District 3, northeast Arkansas (Clay, Craighead, Greene, Independence, Jackson, Lawrence, Mississippi, Poinsett, Randolph, and White counties); District 6, east-central Arkansas (Arkansas, Crittenden, Cross, Lee, Lonoke, Monroe, Phillips, Prairie, St. Francis, and Woodruff counties); District 9, southeast Arkansas (Ashley, Chicot, Desha, Drew, Jefferson, and Lincoln counties), and "Other" (counties outside of Districts 3, 6, and 9, or alternatively counties outside of eastern Arkansas). Finally, comparisons are made of rice prevented-planting acres for all counties in eastern Arkansas (Districts 3, 6, and 9) for the years 2019 and 2020.

Results and Discussion

Arkansas rice-planted, harvested, and prevented-planting acres are presented for the years 2011 through 2020 in Table 1 and Fig. 1. The difference in planted and harvested rice acres in Table 1 and Fig. 1 represents failed acres, which are defined as acreage that was timely planted with the intent to harvest but resulted in crop failure before harvest due to disaster-related conditions (USDA-FSA, 2018). Failed rice acres are typically small across years due to rice being an irrigated crop. Planted rice acres varied considerably over the ten-year period, ranging from a low of 1.066 million acres in 2013 to a high of 1.523 million acres in 2016. Planted rice acres vary by year due to a wide variety of factors, including weather, water availability, expectations about the rice price, and expectations about prices for competing crops, namely soybean and corn (Gautam and Watkins, 2020).

Rice prevented-planting acres also varied considerably over the ten-year period. Rice prevented-planting acres were higher during years with cold, wet springs or extreme flooding (2011, 2013, 2015, 2017, 2019, and 2020) but measurably lower during years with warm or dry springs, where rice planting dates tended to conform with or occur ahead of 5-year average planting dates (2012, 2014, 2016, and 2018). Rice prevented-plantings ranged from less than 1,000 acres in 2012 (a drought year) to a record 512 thousand acres in 2019 (a year experiencing excessive precipitation and flooding throughout the growing season). Rice prevented-plantings in three of the ten study years (2019, 2020, and 2013) represent historical records for Arkansas (517 thousand acres in 2019, 373 thousand acres in 2020, and 303 thousand acres in 2013). Large numbers of rice prevented-planting acres were also recorded in 2015 (270 thousand acres), 2011 (266 acres),

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and 2017 (219 acres). Thus, most years in the decade experienced periods of extreme precipitation and/or flooding that significantly impacted rice plantings during the growing season.

Arkansas rice planted acres are presented by crop year and statistical reporting district in Fig. 2. Rice planted acres are the greatest each year in District 3 (northeast Arkansas), followed by District 6 (east-central Arkansas). These two regions accounted on average for 87% of rice planted acres in Arkansas during the ten-year period, with District 3 accounting for 47% and District 6 accounting for 40%. Rice prevented-planting acres are presented by crop year and statistical reporting district in Fig. 3. With the exception of 2012, when prevented plantings were negligible, rice prevented-plantings are measurably greatest each year in District 3 (northeast Arkansas) followed by District 6 (east-central Arkansas). Rice prevented plantings in District 3 on average accounted for 63% of total rice prevented-plantings in Arkansas during the ten-year period, indicating the majority of rice prevented-plantings occurring in any given year were located in eastern Arkansas. The majority of rice prevented-plantings occurring in eastern Arkansas is due in large part to numerous rivers in this region (Cache, Black, L'Anguille, St. Francis, and White Rivers) that are prone to flooding during heavy rainfall events.

Rice prevented-planting acres are presented by county in eastern Arkansas for 2019 and 2020 in Fig. 4 and Fig. 5, respectively. Counties are ordered from highest to lowest rice prevented-planting acres in both figures. Both figures demonstrate that counties with the largest numbers of rice prevented-planting acres are generally located in District 3 (northeast Arkansas). Jackson and Lawrence counties alone account for 125 thousand and 108 thousand rice prevented-planting acres (24% and 29% of total Arkansas rice prevented-plantings), respectively, in 2019 and 2020. Both are significant rice-producing counties in the state, ranking in most years either in the state's top five or the state's top 10 rice counties in terms of rice production (USDA-NASS, 2021).

Practical Applications

Periods of extreme precipitation and flooding frequently occurred during the 2011 through 2020 decade, and these extreme weather events resulted in significant numbers of rice prevented-plantings in six of the ten study years evaluated. It is unknown whether the next ten years will result in similar weather patterns. However, the 2011 through 2020 decade did demonstrate that rice production in much of the state is vulnerable to extreme precipitation and flooding, particularly in northeastern Arkansas, where rice is grown in close proximity to numerous rivers prone to flooding during heavy rainfall events. Northeastern Arkansas is the largest rice-producing region in Arkansas, accounting on average for 47% of all rice-planted acres in the state. The results of this study, thus, highlight the need for better flood prevention and flood control infrastructure in this region of the state.

Acknowledgments

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Table 1. Arkansas rice planted, harvested, and prevented planted acres, 2011–2020.

Year	Planted	Harvested	Prevented
	------------------------1,000 acres------------------------		
2011	1,189	1,151	266
2012	1,279	1,278	0
2013	1,066	1,055	303
2014	1,475	1,471	108
2015	1,299	1,280	270
2016	1,538	1,514	60
2017	1,153	1,102	219
2018	1,435	1,423	43
2019	1,149	1,123	512
2020	1,452	1,435	373
Mean	1,304	1,283	215
Standard Deviation	163	170	162
Coefficient of Variance	12.5	13.2	75.4
Minimum	1,066	1,055	0
Median	1,289	1,279	242
Maximum	1,538	1,514	512

Source: USDA-FSA, 2021.

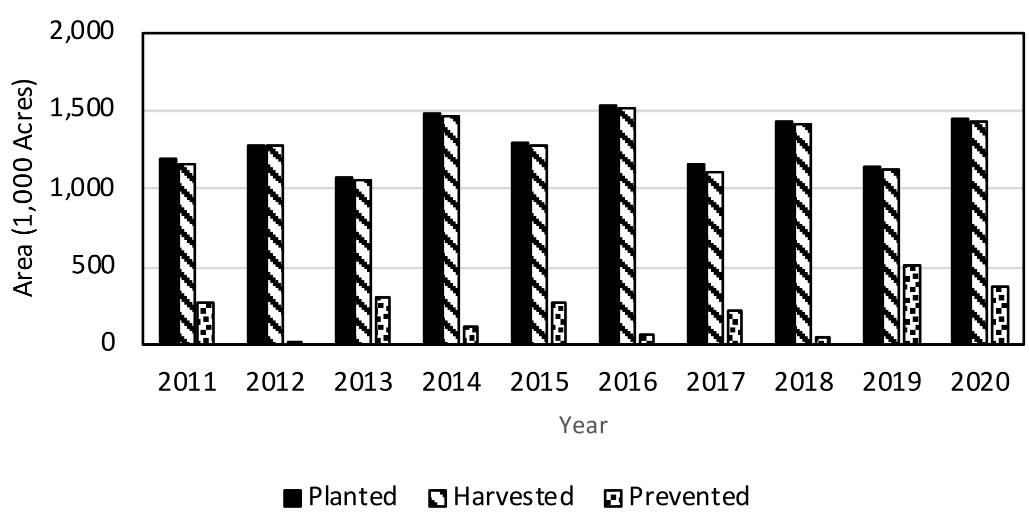

Fig. 1. Arkansas rice planted, harvested, and prevented planting acres, 2011–2020 (USDA-FSA, 2021) .

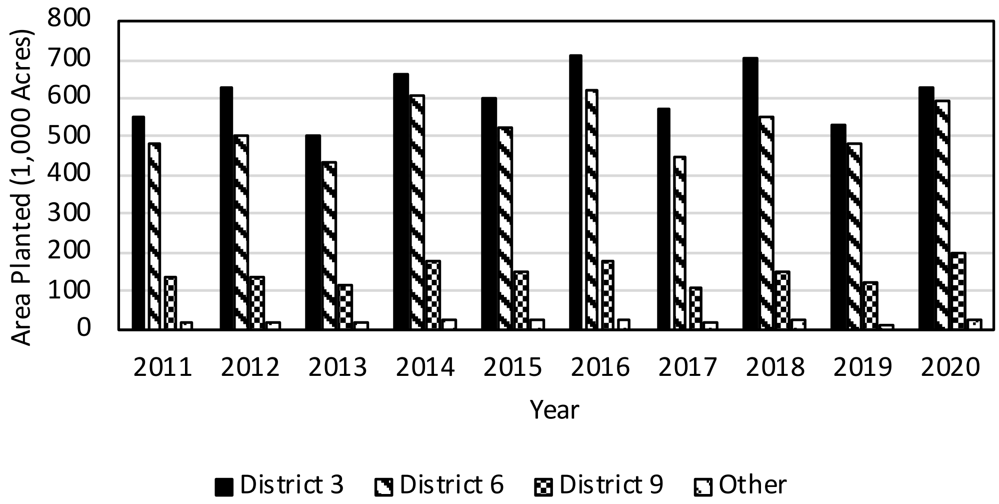

Fig. 2. Arkansas rice planted acres by Arkansas Statistical Reporting District, 2011–2020 (District 3 = northeast Arkansas, District 6 = east-central Arkansas, District 9 = southeast Arkansas, and Other = counties outside eastern Arkansas (USDA-FSA, 2021).

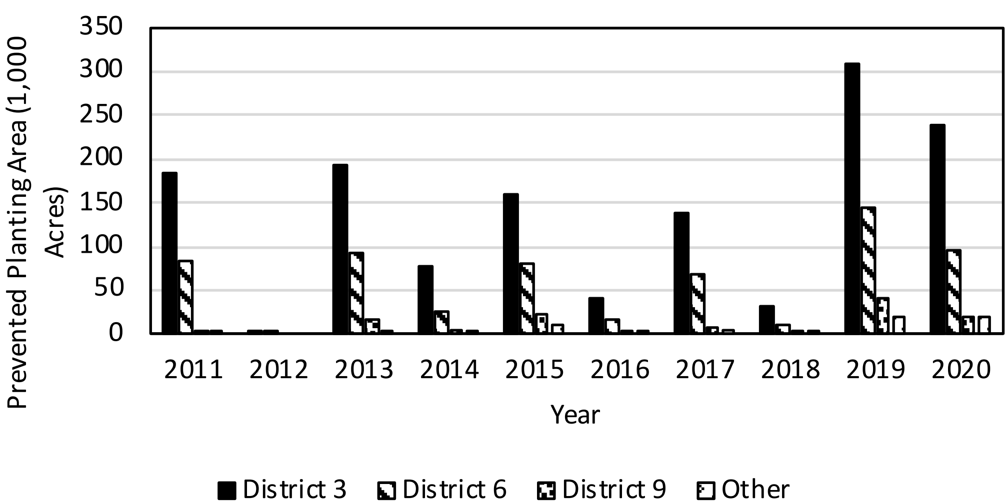

Fig. 3. Arkansas rice prevented planting acres by Arkansas Statistical Reporting District, 2011–2020 (District 3 = northeast Arkansas, District 6 = east-central Arkansas, District 9 = southeast Arkansas, and Other = counties outside eastern Arkansas (USDA-FSA, 2021).

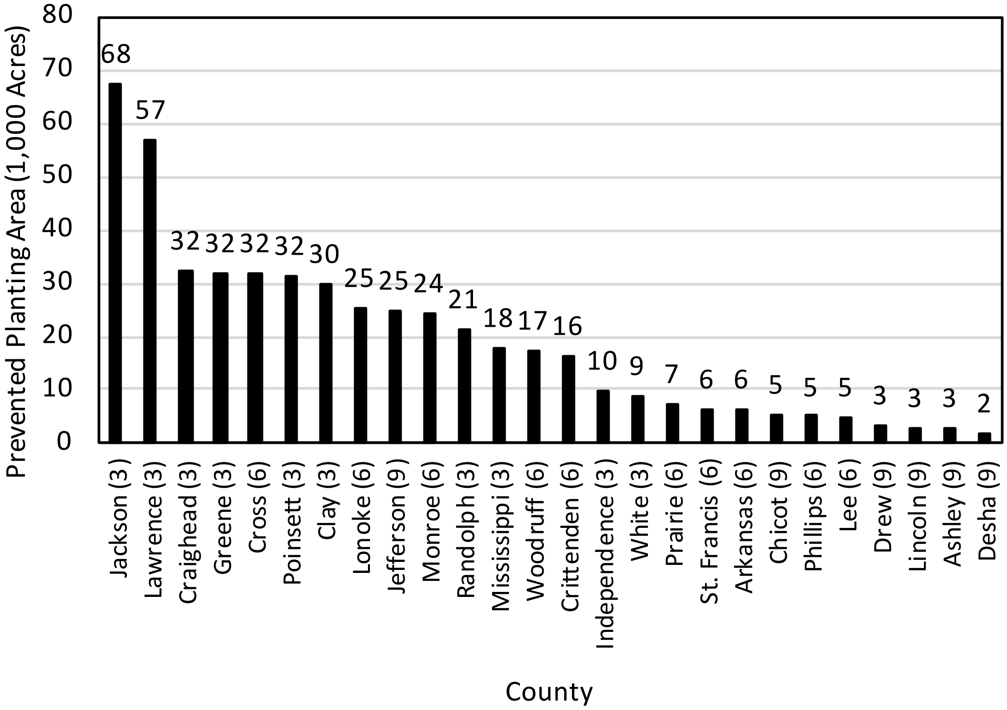

Fig. 4. Rice prevented planting acres by county in eastern Arkansas, 2019 (numbers in parentheses designate Arkansas Statistical Reporting District 3 [northeast Arkansas], 6 [east-central Arkansas], and 9 [southeast Arkansas]. Numbers above bars are rice prevented planting acres for each county (USDA-FSA, 2021).

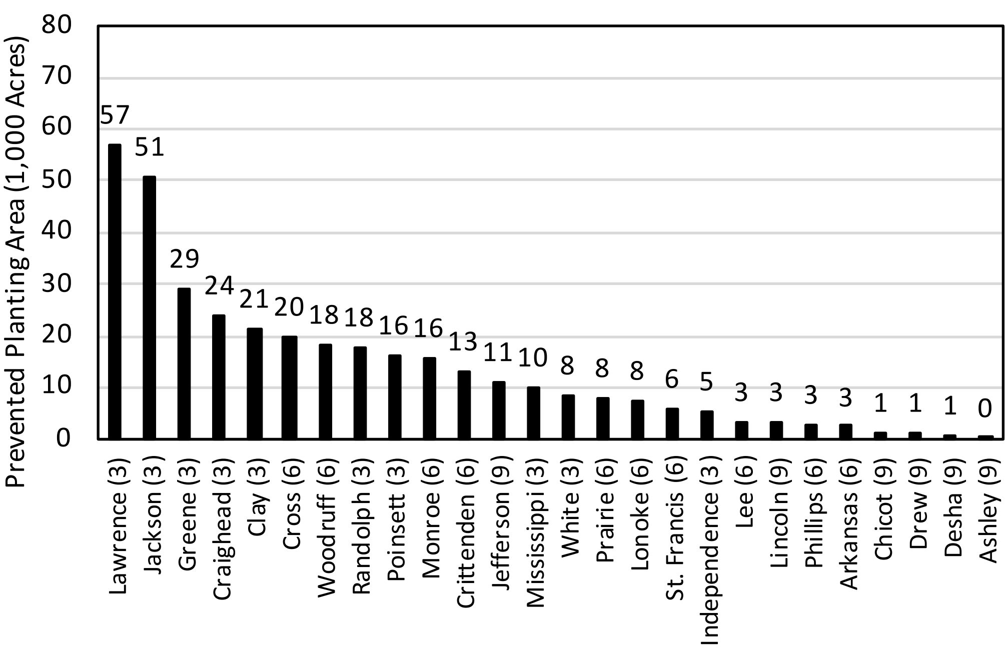

Fig. 5. Rice prevented planting acres by county in eastern Arkansas, 2020 (numbers in parentheses designate Arkansas Statistical Reporting District 3 [northeast Arkansas], 6 [east-central Arkansas], and 9 [southeast Arkansas] Numbers above bars are rice prevented planting acres for each county (USDA-FSA, 2021).

APPENDIX: RICE RESEARCH PROPOSALS

2020-2021 Rice Research Proposals

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
Non-Ecosystems				
T. Barber	J. Norsworthy and T. Butts	A team approach to improved weed management in rice	2 of 3	235,000
J. Hardke		Agronomic production practices for rice	2 of 3	99,500
J. Hardke		DD50 thermal unit thresholds and seeding date effects for new cultivars	2 of 3	60,000
J. Hardke	T. Roberts	Optimum rice plant spacing and seeding rate	2 of 3	24,000
J. Hardke	T. Roberts	Nitrogen recommendations for new rice cultivars	2 of 3	57,000
N. Bateman	G. Lorenz and B. Thrash	Rice insect control, 2020	2 of 3	118,000
T. Roberts	J. Hardke	Nitrogen management tools for Arkansas rice producers	2 of 3	105,000
T. Roberts	J. Hardke	Rice fertilization-developing novel methods to assess nutrient availability to Arkansas rice	2 of 3	56,000
Y. Wamishe	J. Hardke	Evaluation of fungicide application timing and coverage to suppress false smut and sheath blight of rice	2 of 3	25,000
B. Watkins	A. Durand-Morat and R. Mane	Economic analysis of Arkansas rice farms	2 of 3	55,000
K. Moldenhauer		Breeding and evaluation for improved rice varieties (Project No. ARK02530)	2 of 3	299,000
K. Moldenhauer	X. Sha and E. Shakiba	Quality analysis for rice breeding and genetics	1 of 1	115,000
X. Sha		Development of superior medium-grain and long-grain rice varieties for Arkansas and the mid-south	2 of 3	299,000
E. Shakiba		Breeding and evaluation for hybrid rice adapted to the southern USA	3 of 3	180,000
E. Shakiba	K. Moldenhauer and X. Sha	Marker-assisted selection for advanced rice breeding and genetics	2 of 3	135,000
J. Hardke		Arkansas rice performance trials	2 of 3	99,000
K. Moldenhauer	Y. Wamishe	Rice breeding and pathology tech support	2 of 3	130,000
Y. Wamishe	J. Hardke	Evaluation of contemporary rice to straighthead, a physiological disorder of unknown cause	2 of 3	10,000
C. Rojas	A. Pereira	Investigating genetic basis of resistance to bacterial panicle blight of rice under heat stress conditions	2 of 3	25,000
C. Rojas	A. Rojas	Control of rice diseases in Arkansas by using antagonistic bacteria and products derived from them	2 of 3	24,000

Continued

2020-2021 Rice Research Proposals, continued.

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
Ecosystems				
A. Pereira	P. Counce and K. Moldenhauer	Improving grain yield and quality under high nighttime temperature using functional gene markers	2 of 3	30,000
J. Hardke	B. Watkins, R. Mazzanti, and T. Gautam	Rice research verification program	2 of 3	100,000
T. Siebenmorgen		Identification of cultivar attributes that impact rice drying and milling characteristics	2 of 3	62,000
N. Slaton		Editing and publishing B.R. Wells Rice Research studies (2019)		4,000
V. Ford	B. Watkins	Rice enterprise budgets and production economic analysis	1 of 1	8,500
A. Durand-Morat	B. Watkins and R. Mane	Analysis of farm policy programs and competitiveness of Arkansas and U.S. rice	1 of 1	15,000
J. Hardke	T. Roberts	Agronomics of Alternative Irrigation Strategies for Rice	4 of 5	50,000
C. Henry		Developing and improving irrigation tools for rice	2 of 3	80,000
			Total:	**2,500,000**

DIVISION OF AGRICULTURE

RESEARCH & EXTENSION

University of Arkansas System